

Towards more Resilient Infrastructure Systems: Methods and Tools

Dr Sonia Giovinazzi (*University of Canterbury*)

Dr Deirdre Hart (*University of Canterbury*)

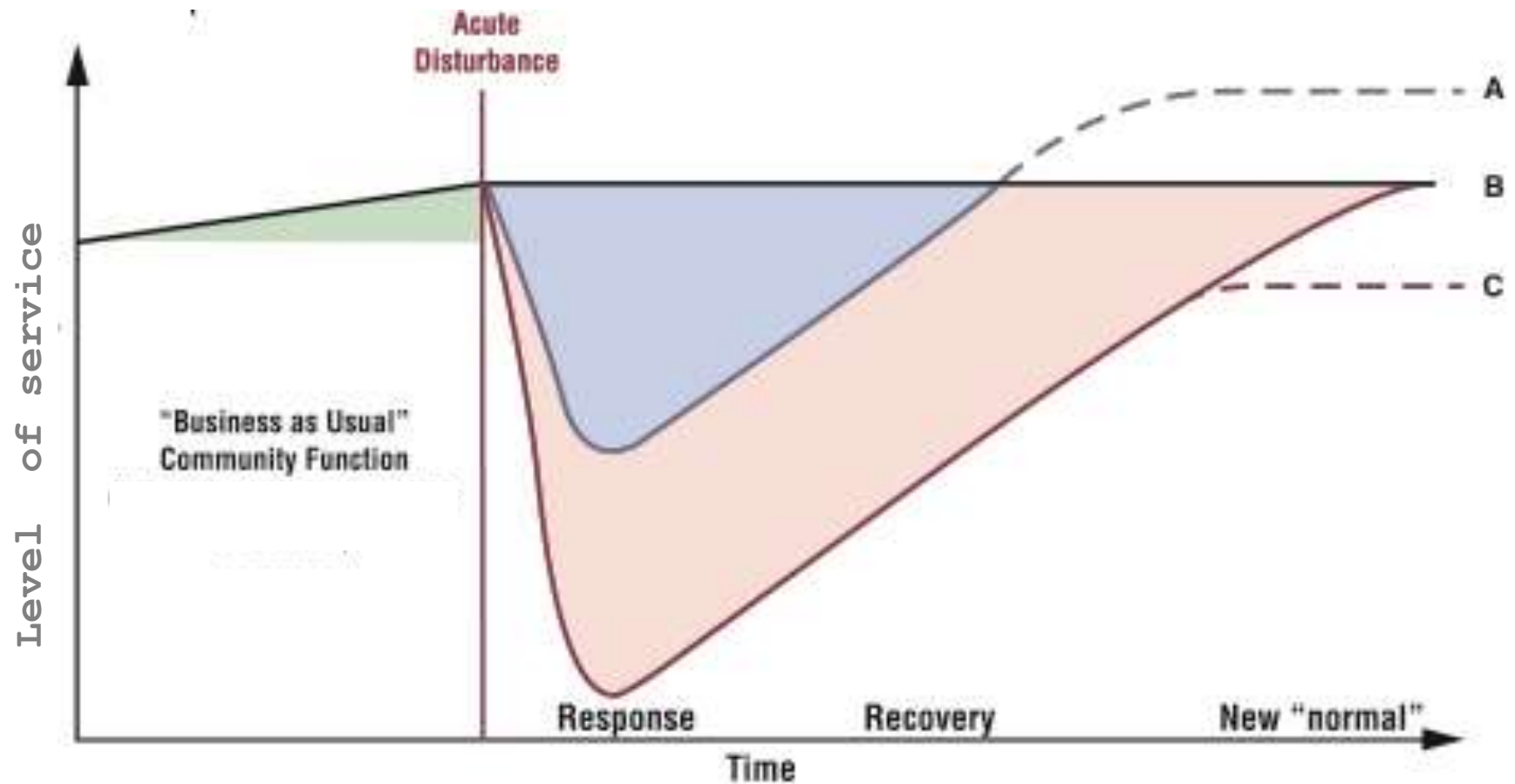
Dr Francesco Cavalieri (*Sapienza University of Rome*)

Indranil Kongar (*University College London*)

Towards more Resilient Infrastructure Systems

Our Aim: Create scientifically-sound, end-user oriented methods and tools:

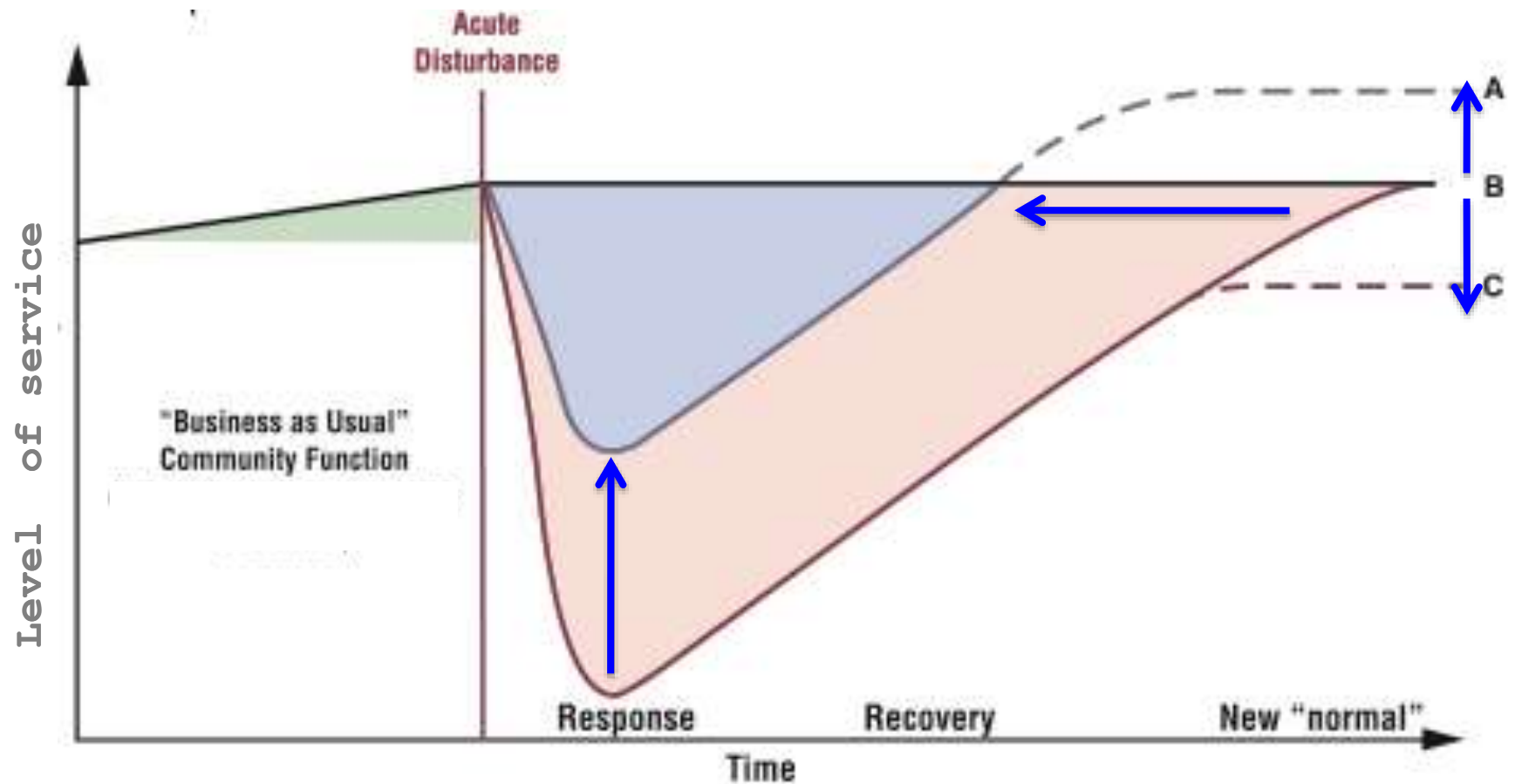
- to support resilience assessments for status-quo infrastructure systems, *and*
- to inform decision making processes towards more resilient infrastructure systems



Towards more Resilient Infrastructure Systems

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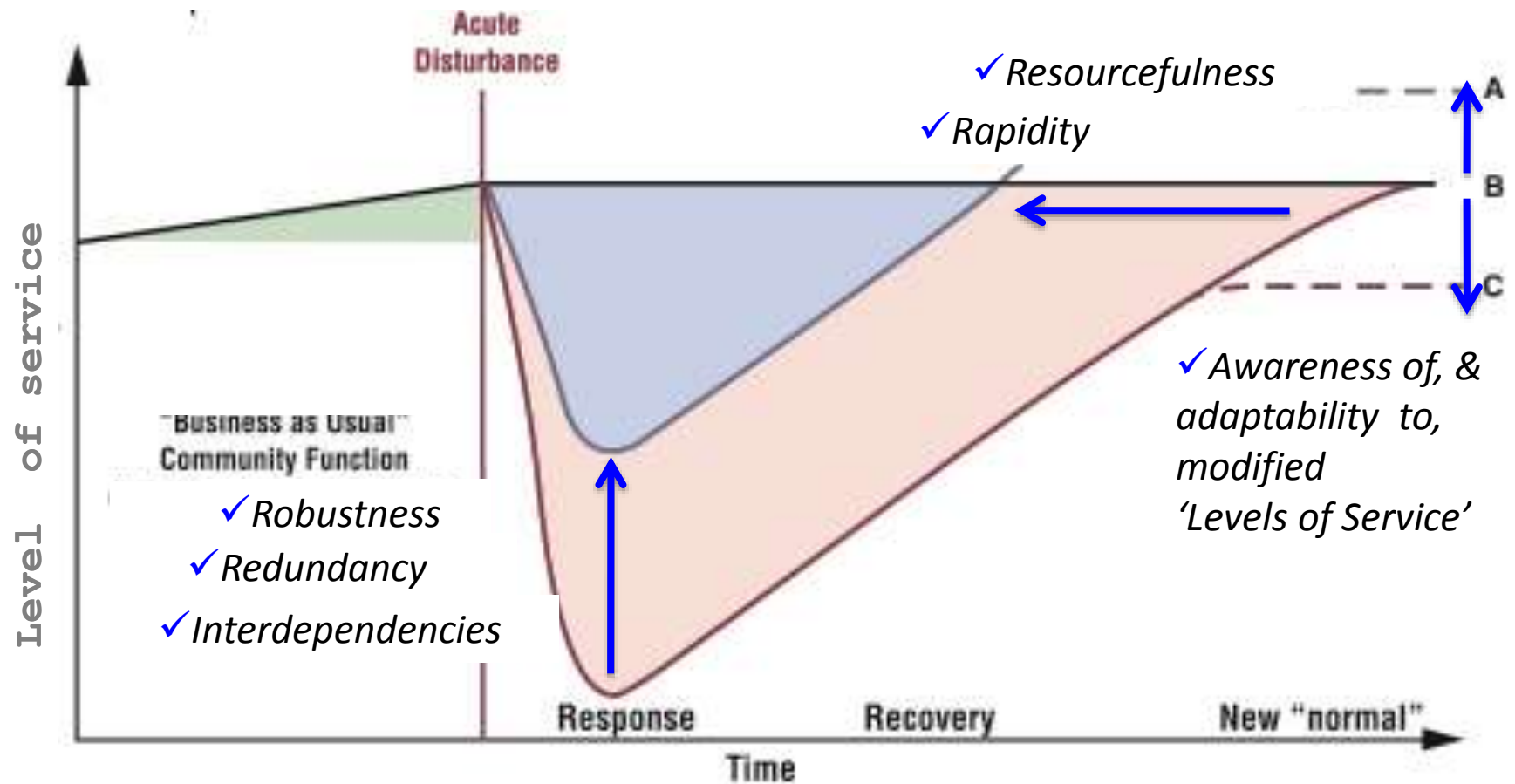
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Towards more Resilient Infrastructure Systems

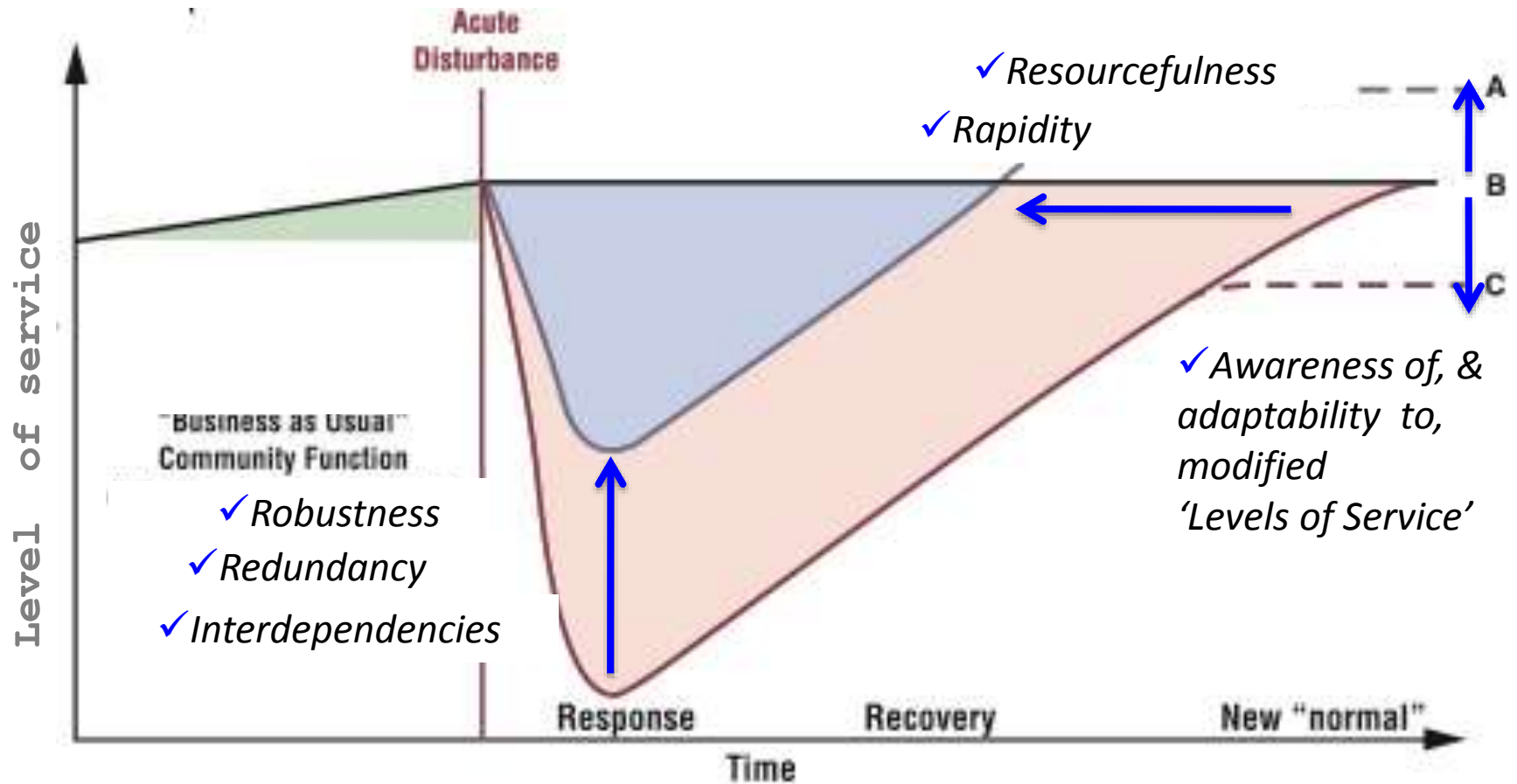
Our Aim: Create scientifically-sound, end-user oriented methods and tools:

- to support resilience assessments for status-quo infrastructure systems, and
- to inform decision making processes towards more resilient infrastructure systems



Towards more Resilient Infrastructure Systems

- Resilience to **multi-hazards** (& shocks) & **cascading effects**
- Integrating '**technical**' dimensions of resilience with 'social', 'organisational', 'economic' dimensions toward an holistic resilience assessment.



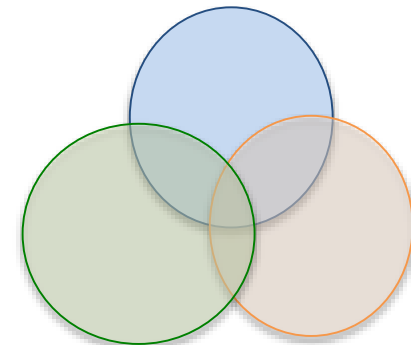
Towards more Resilient Infrastructure Systems

- Resilience to **multi-hazards** (& shocks) & **cascading effects**
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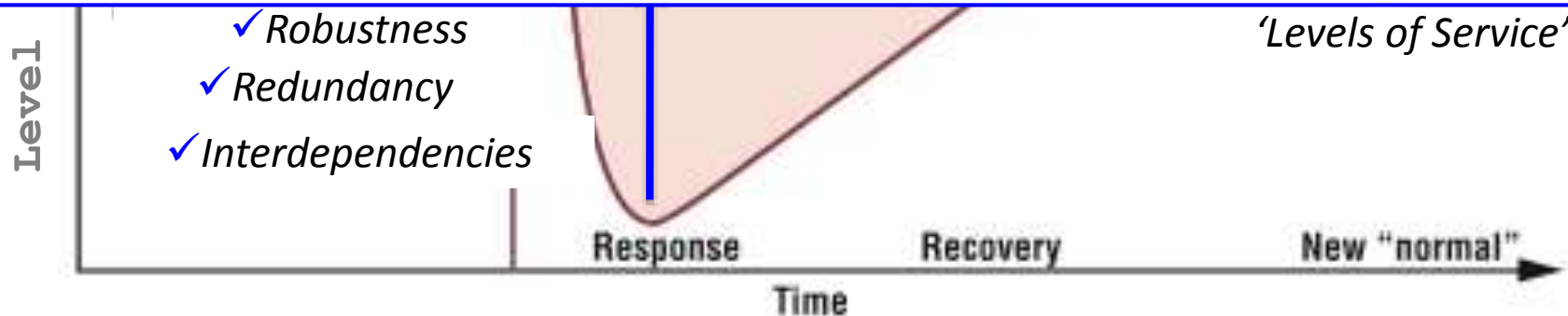
✓ Resourcefulness
✓ Rapidity

Integrated approach:

- 'observation-based' - from evidence & learning to transferable models
- 'analysis-based' - cross-calibration with analytical models
- 'expert-based' - 'reality check' with end-users



'Levels of Service'



Towards more Resilient Infrastructure Systems

On-going Projects and International Collaborations:

- Earthquake-Flood Multi-hazard Impacts on Lifeline Systems following the Canterbury Earthquake Sequence 2010-2011



David Holland
(MSc)



- Projecting Damage and Losses for Buildings and Infrastructures from the Canterbury Earthquake Sequence

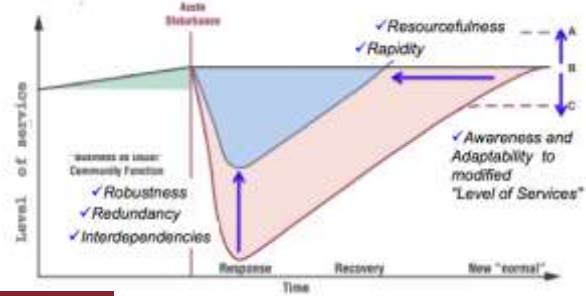


Su Young Ko
(PhD)

A multi-hazard framework for assessing and managing flooding hazard in a seismically active low-lying urban environment



Melanie Liu (PhD)



Decision support system for post-earthquake rehabilitation of sewerage systems: A project management perspective

Adnan Rais (PhD)

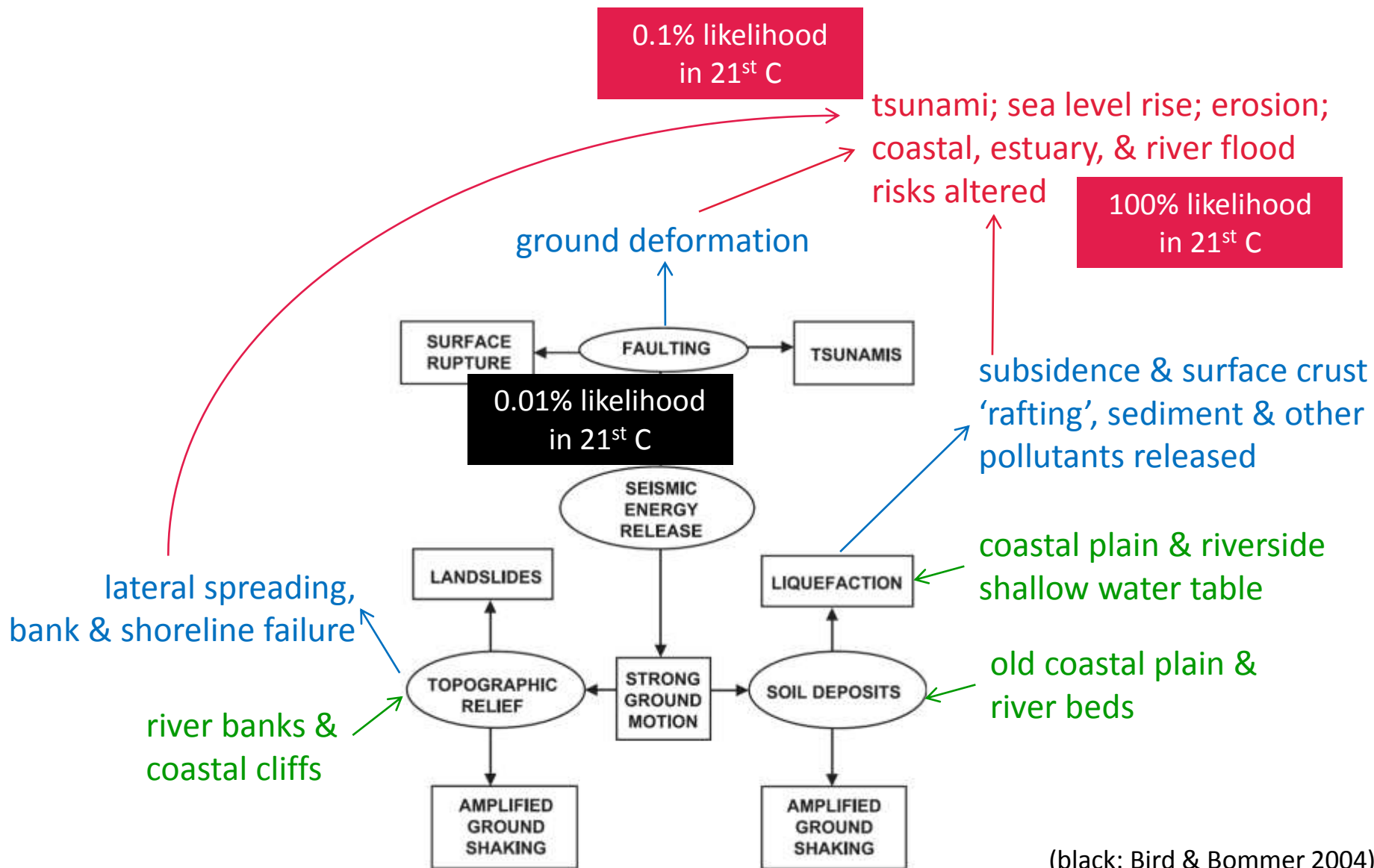


Integrated bridge-utility systems: performance based assessment and mitigation of earthquake-induced physical and functional impacts

Website under construction

Multi-hazards are?

e.g. coastal & river quakes



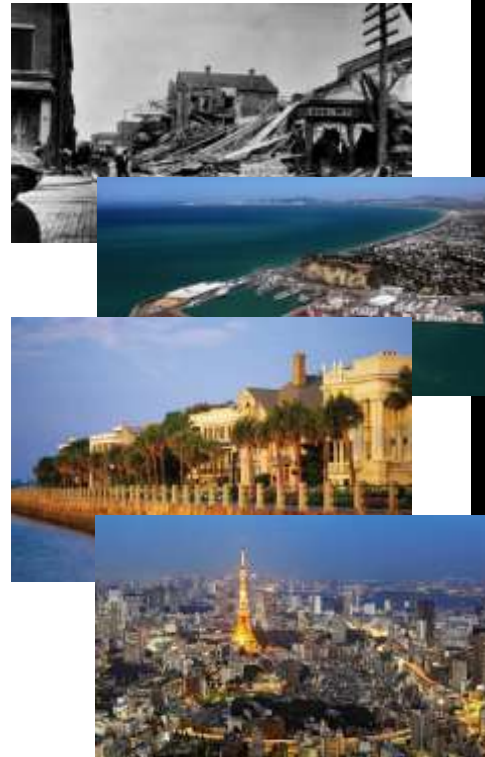
Multi-hazard prone infrastructure?

e.g. coastal settlements



Line demarcates ?

- Holocene coast ~6500 y BP
- Inland extent of heavy lifelines network damage
- Inland limit of increased flooding vulnerability
- Post-sea level rise liquefaction vulnerability zone

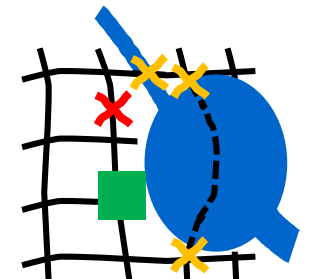


Cities on
seismically-active
recent coastal plains

- Charleston 1886
- Napier 1931
- Anchorage 1964
- Tokyo ???



21st century population
concentration in megacities
vulnerable to coastal quake
multi-hazards



Multi-hazards link the ‘un-linkable’

Lifelines & Increased Flooding Vulnerability (IFV) Project

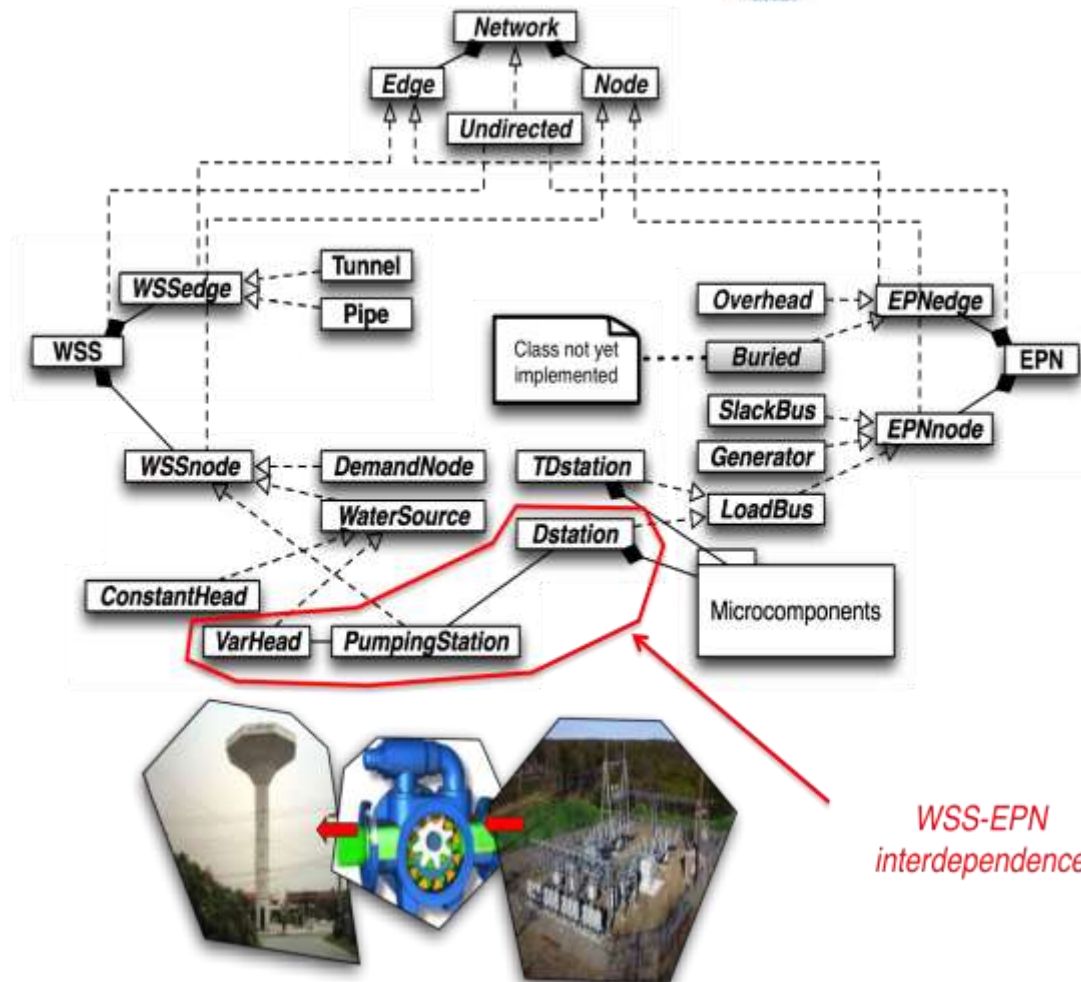
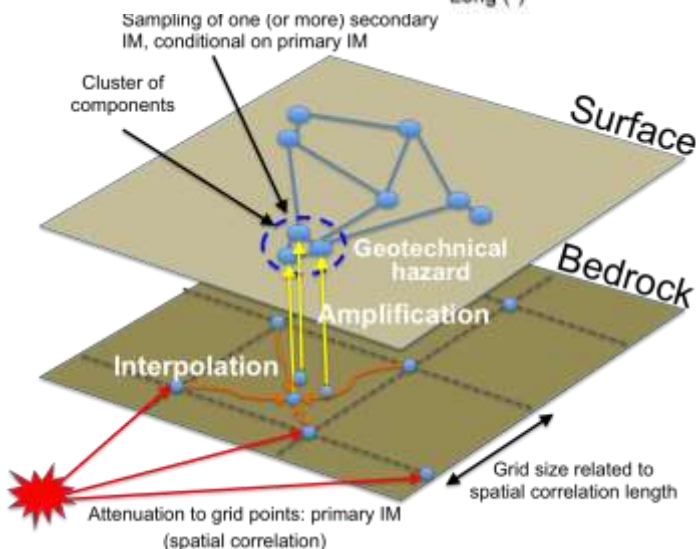
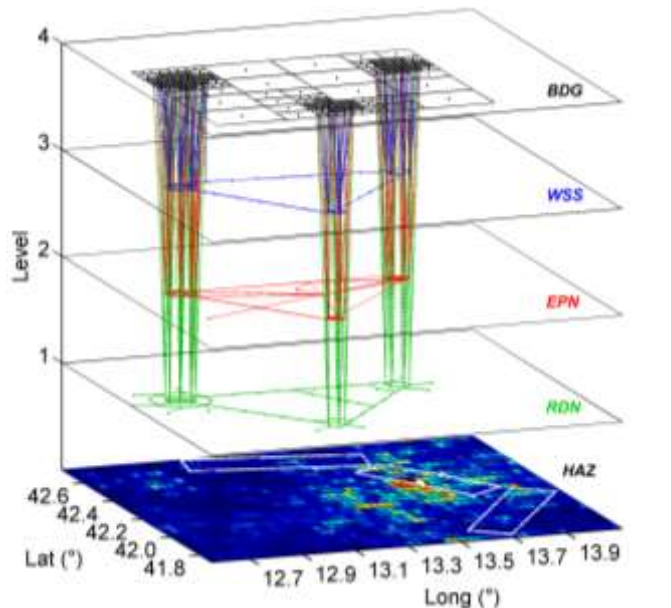
- terrain deformation (river & land profile changes, runoff, swales, pipe strain)
- liquefaction
- river channel capacity loss via constriction from rafting & bed uplift
- relative sea level rise: land levels, estuary/ river drainage, groundwater depths
- pipe network damage (breaks, sediment load & deposits, connection failures)
- domino effects of subterranean erosion (roads), waste water interactions
- 2014 GEER Report http://www.geerassociation.org/GEER_Post%20EQ%20Reports/Christchurch_Flood_2014/index.html
- 2013-15 IFV research by Holland (MSc) & Ko (PhD) drainage network & stormwater foci: <http://www.civil.canterbury.ac.nz/postgrads/sko.shtml>
- 2015-16 TCLEE monograph



Object-Oriented Framework for Infrastructure Modelling and Simulation (OOFIMS)

The software (in Matlab language) was developed in Rome within SYNER-G

<https://sites.google.com/a/uniroma1.it/oofims/home>



WSS-EPN
interdependence

Christchurch stormwater network

Prediction of physical damage and overflow

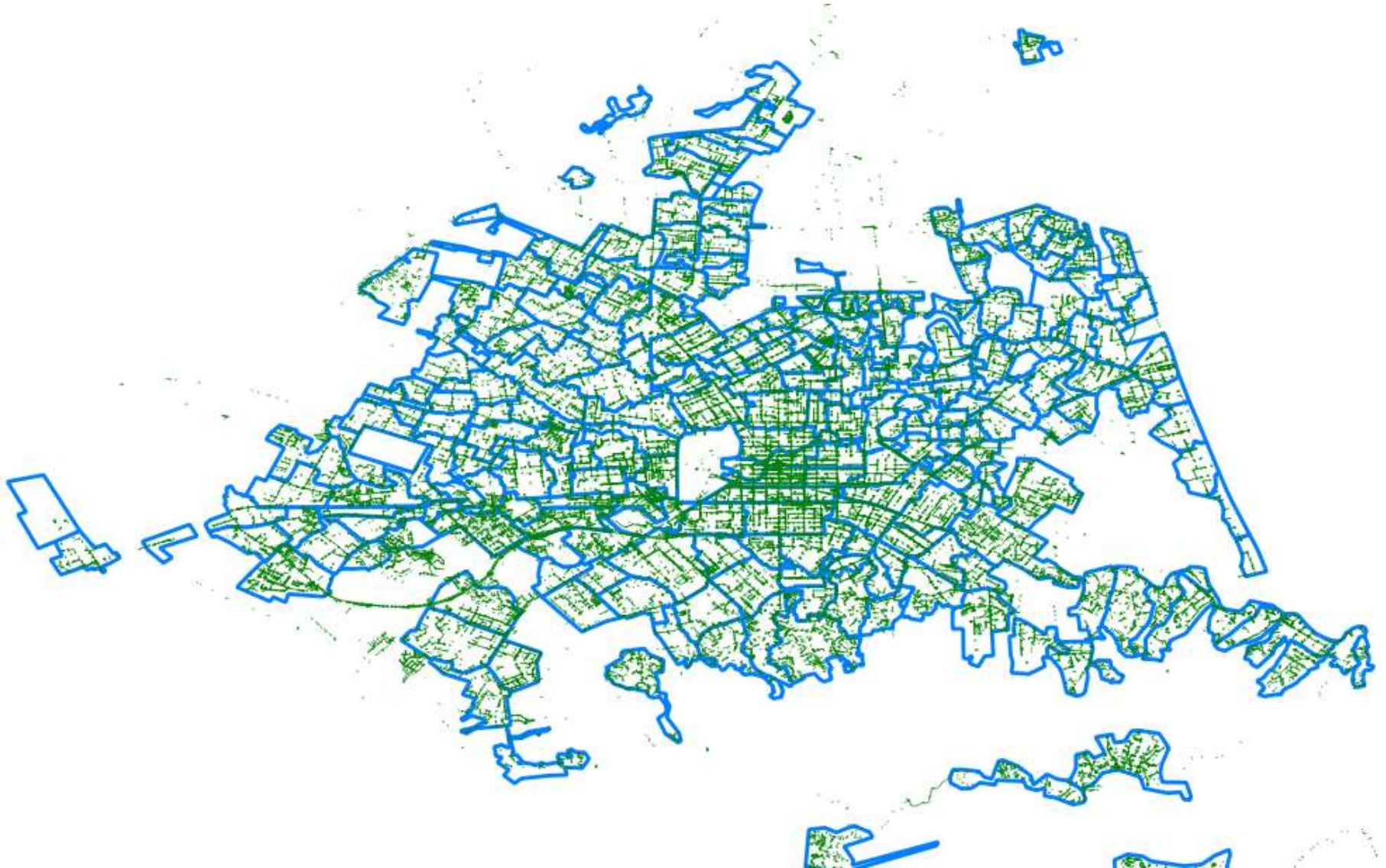
Network topology



Christchurch stormwater network

Prediction of physical damage and overflow

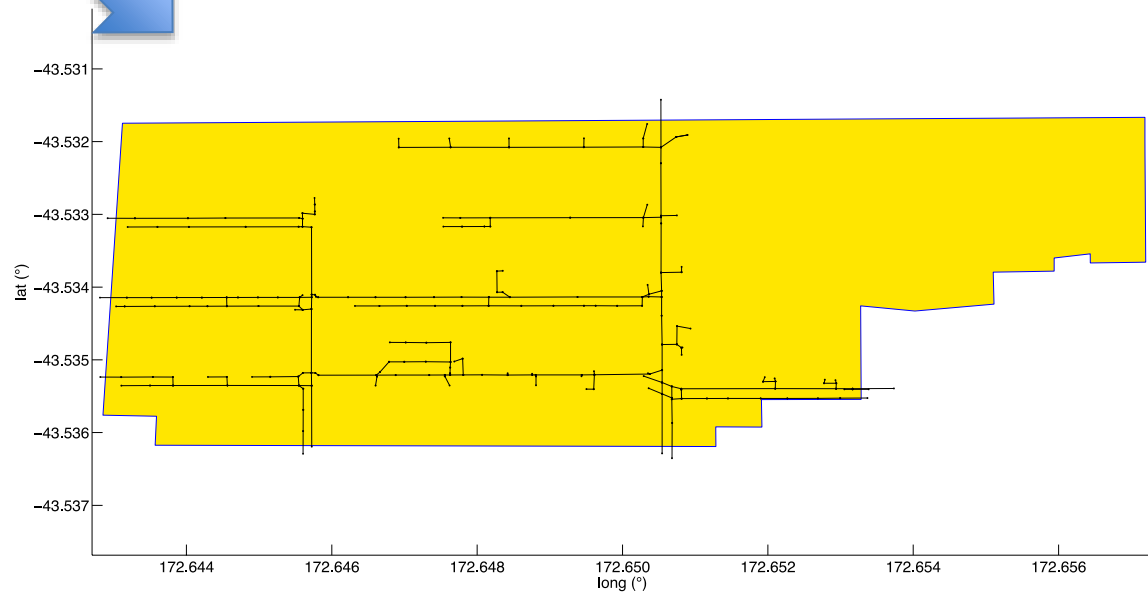
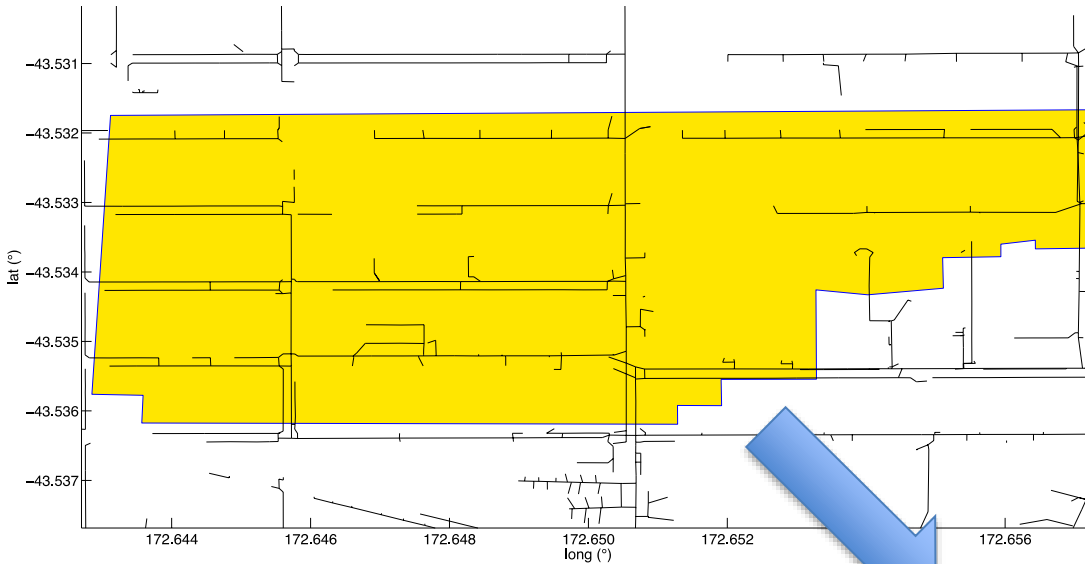
Network subcatchments



Christchurch stormwater network

Prediction of physical damage and overflow

Analysis of a portion of the network enclosed within one CBD subcatchment

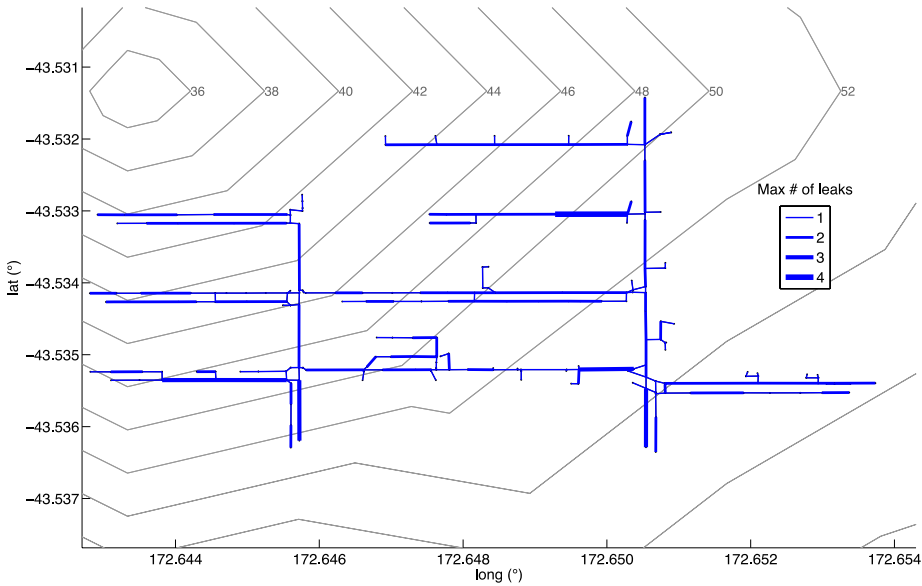


Christchurch stormwater network

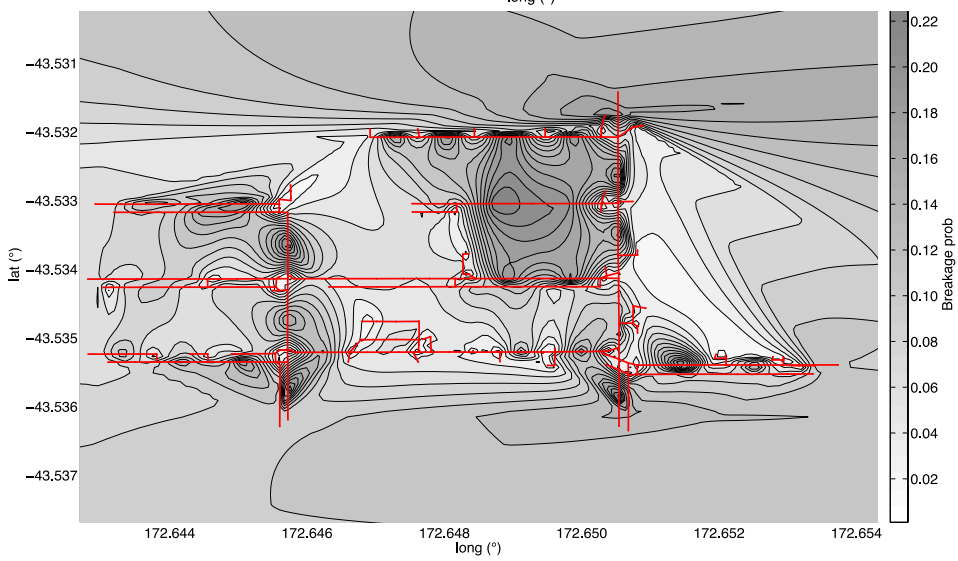
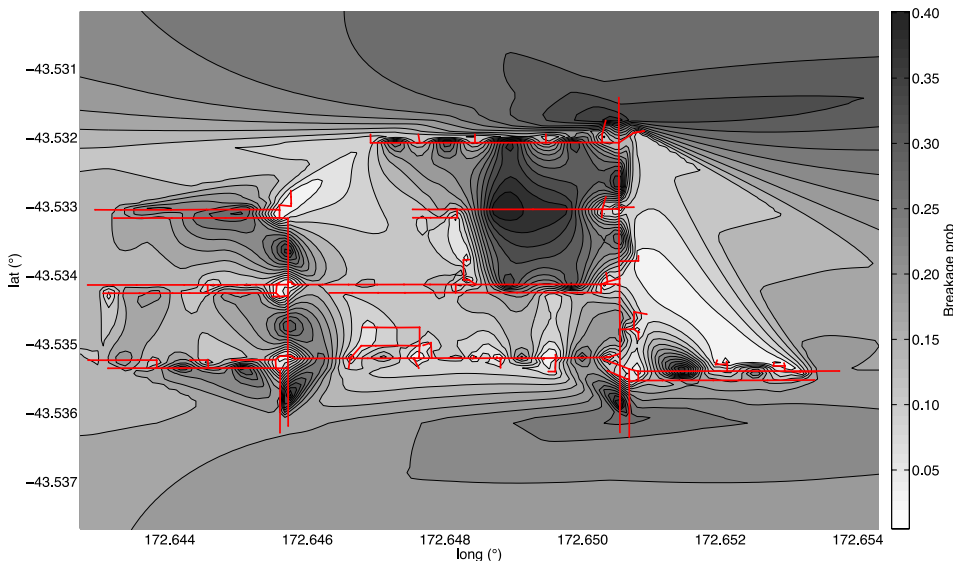
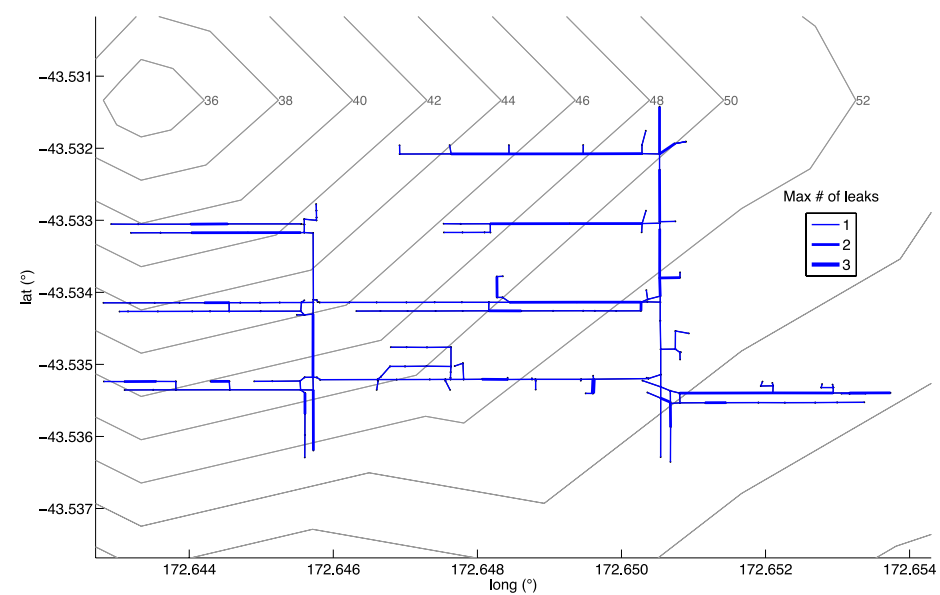
Prediction of physical damage and overflow

Physical damage indicators: maximum expected number of leaks and breakage probability

Original materials

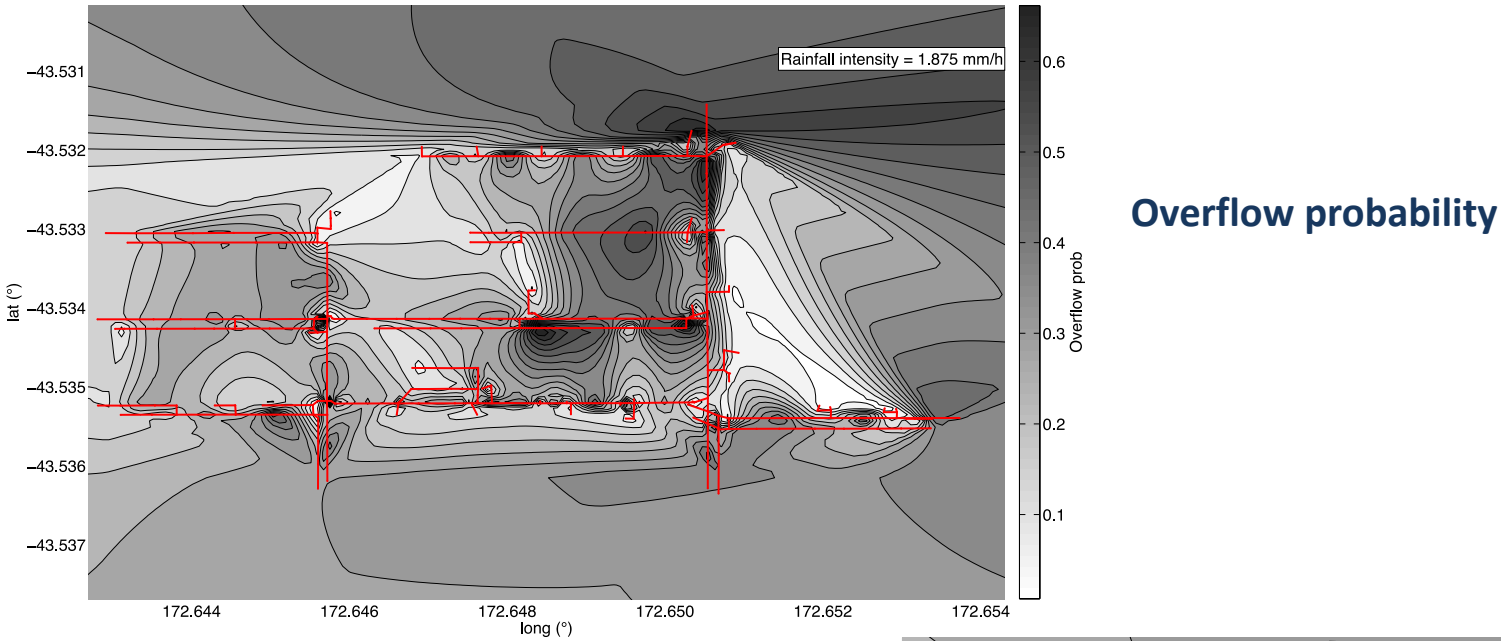


All pipes made of ductile iron

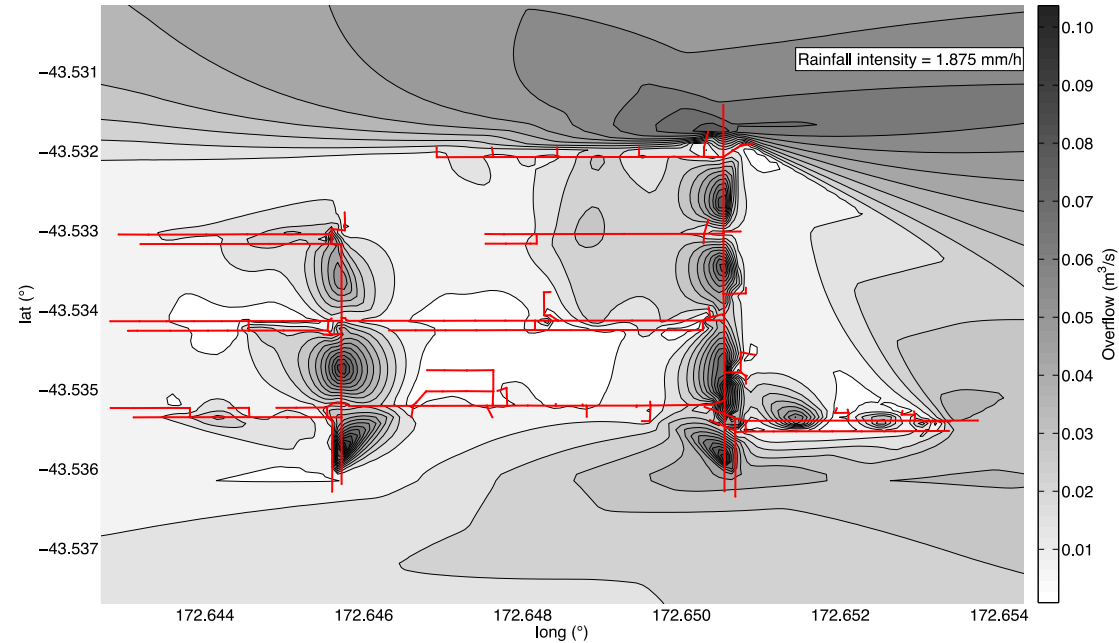


Christchurch stormwater network

Prediction of physical damage and overflow

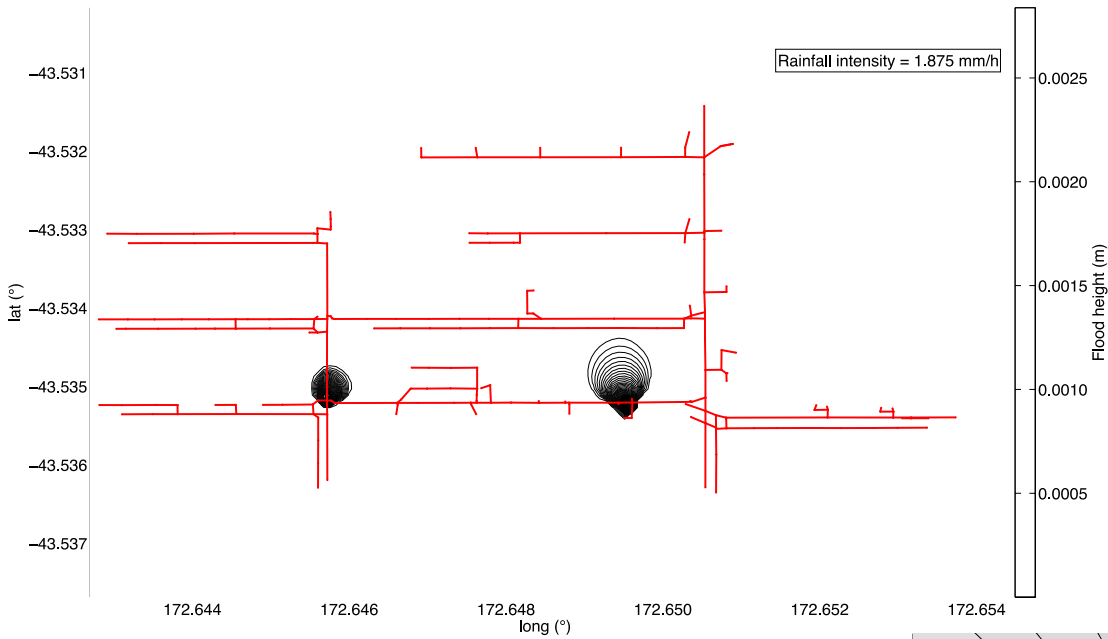


Expected overflow during a given rain event

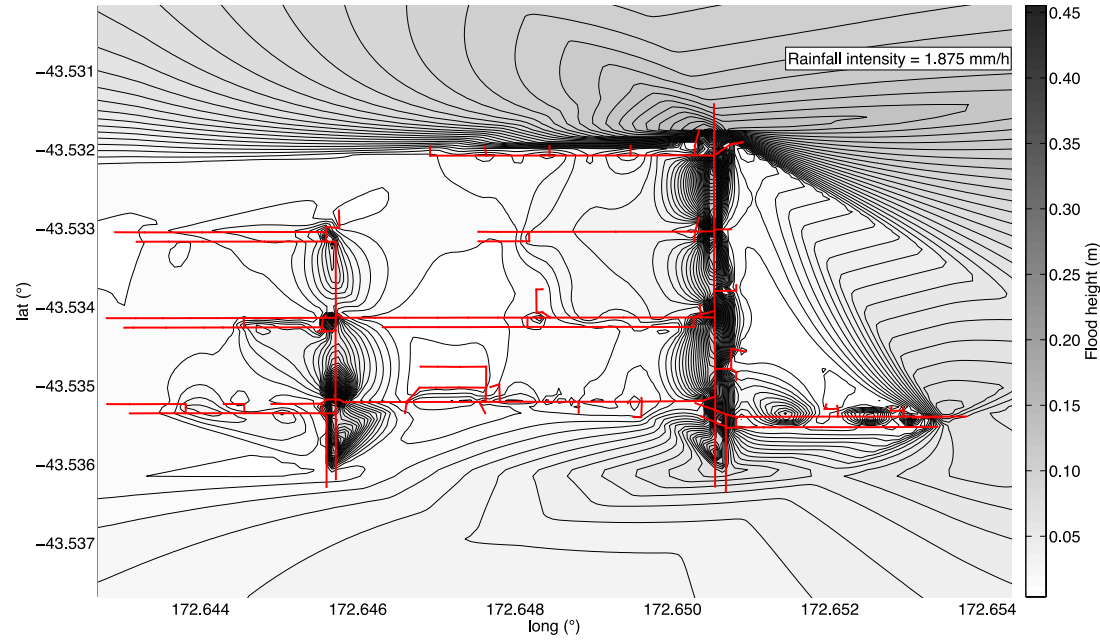


Christchurch stormwater network

Prediction of physical damage and overflow



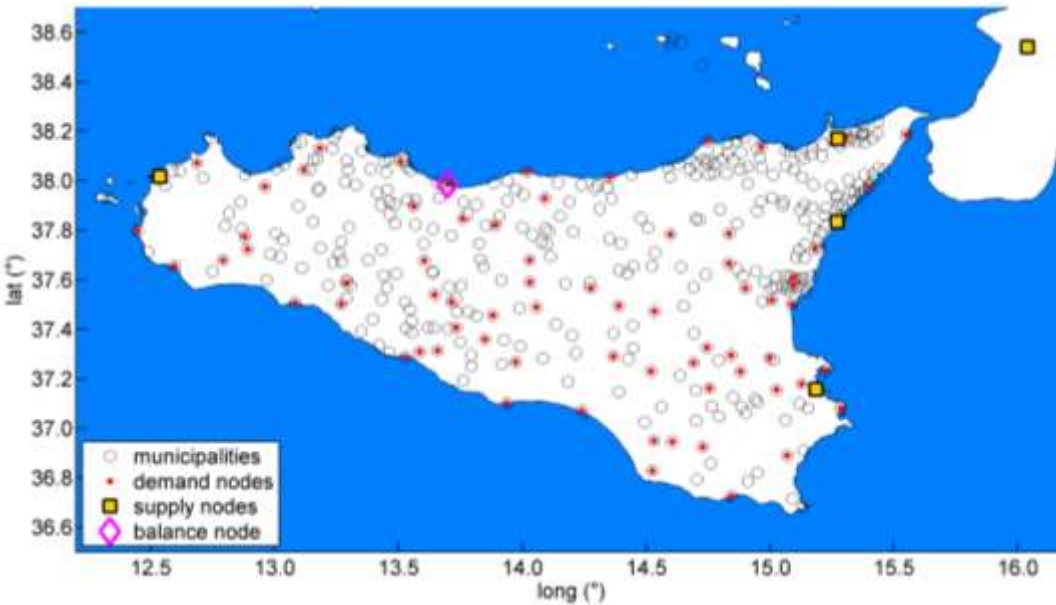
Flood height before and after
the earthquake, to assess the
**Increased Flooding
Vulnerability (IFV)**



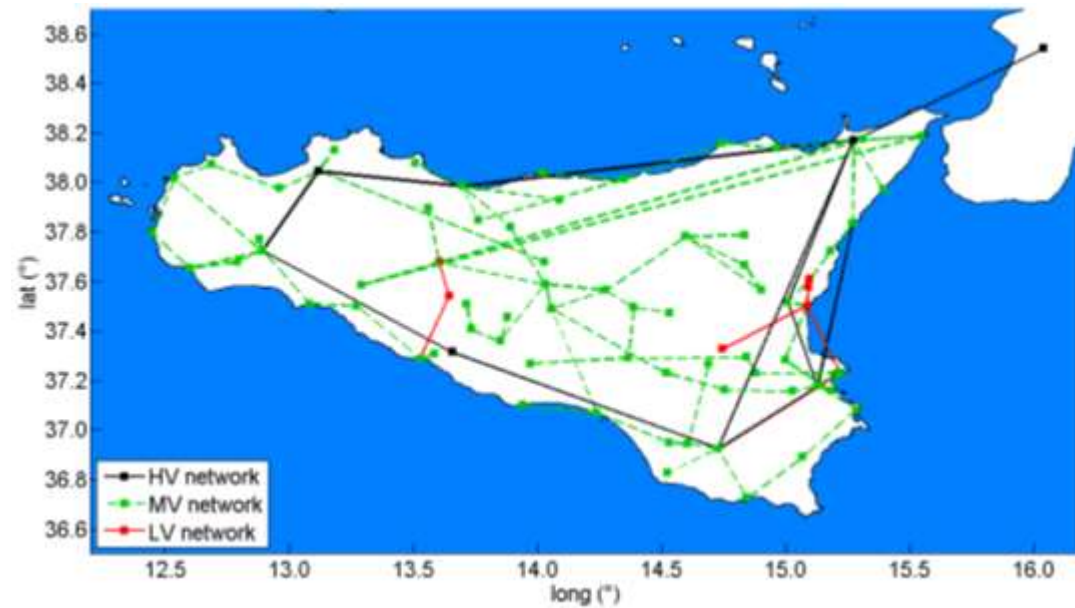
Electric power network case studies

Prediction of physical damage, connectivity and serviceability indicators

Case study #1: Sicily power network



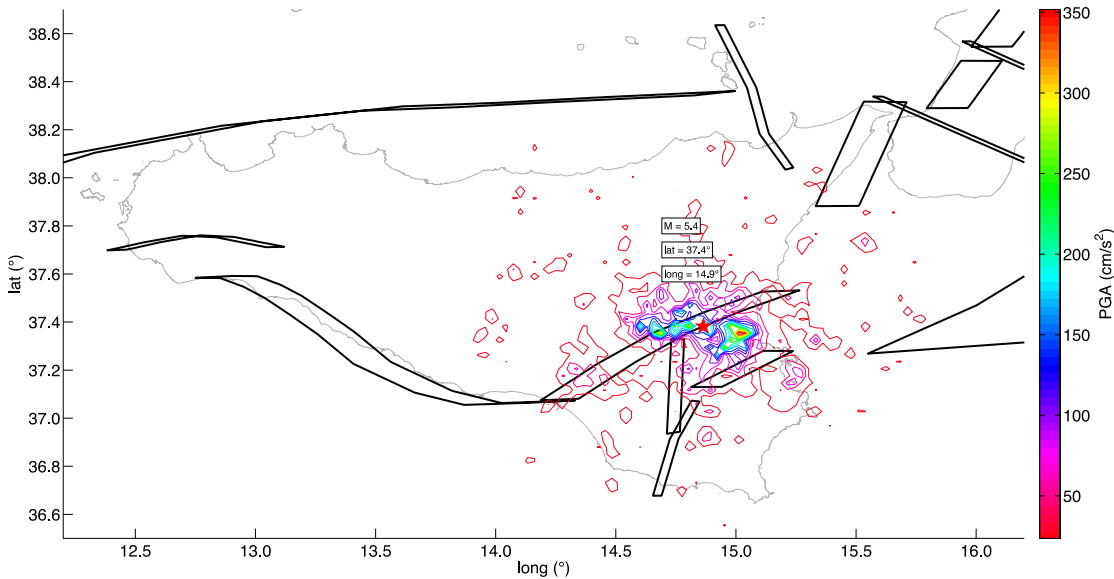
Network nodes and lines



Electric power network case studies

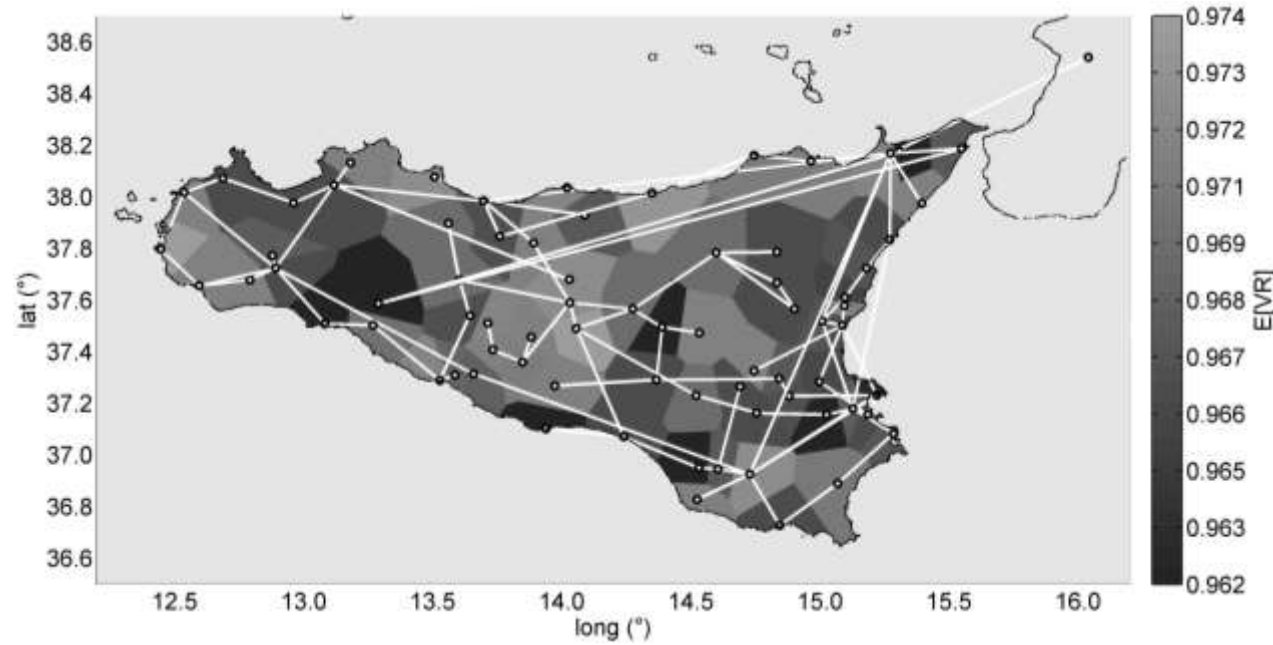
Prediction of physical damage, connectivity and serviceability indicators

Case study #1: Sicily power network



Faults affecting Sicily and simulated PGA shake map

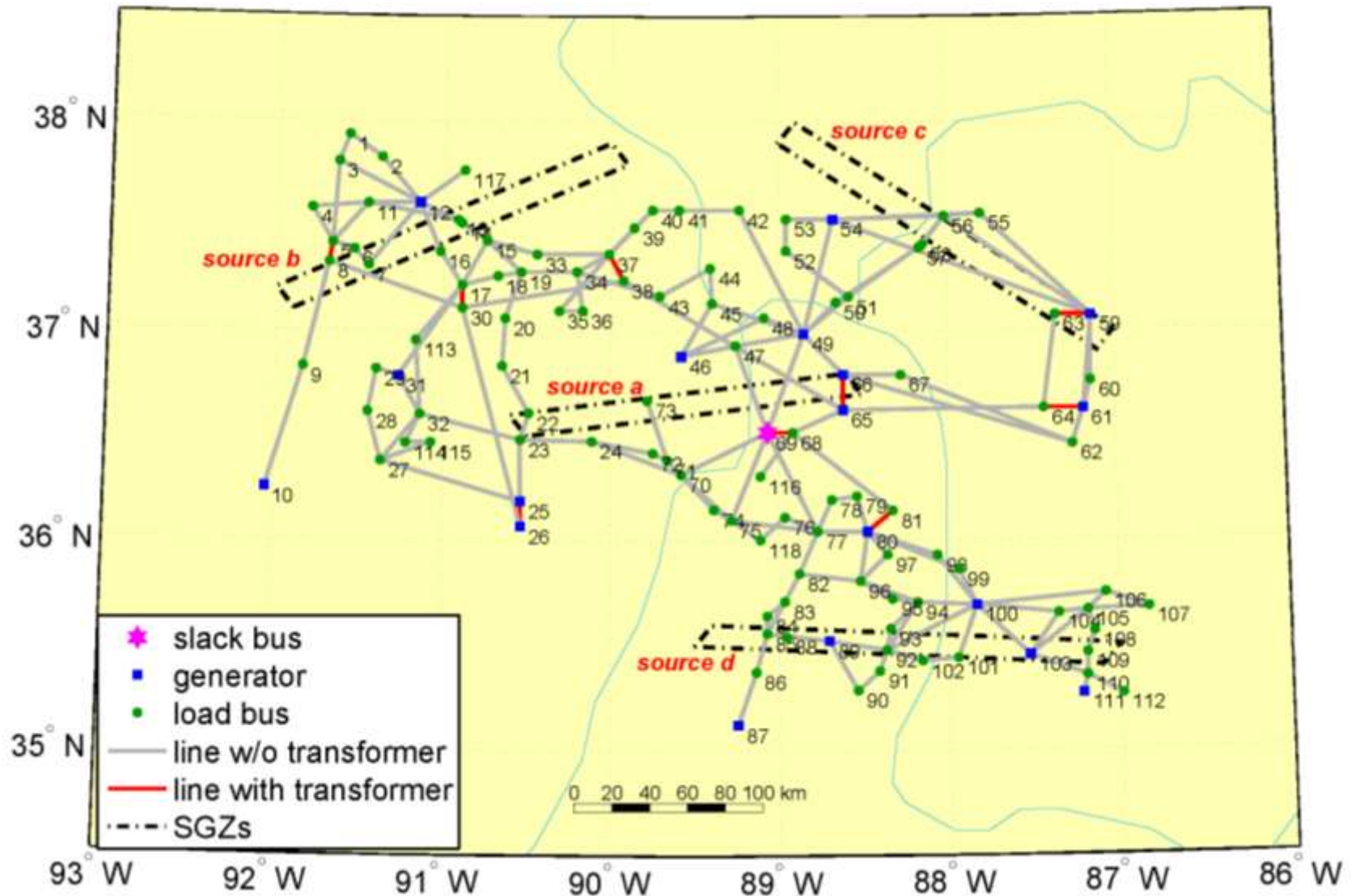
Power flow analysis,
Mean Voltage Ratio (VR),
Voronoi diagram



Electric power network case studies

Prediction of physical damage, connectivity and serviceability indicators

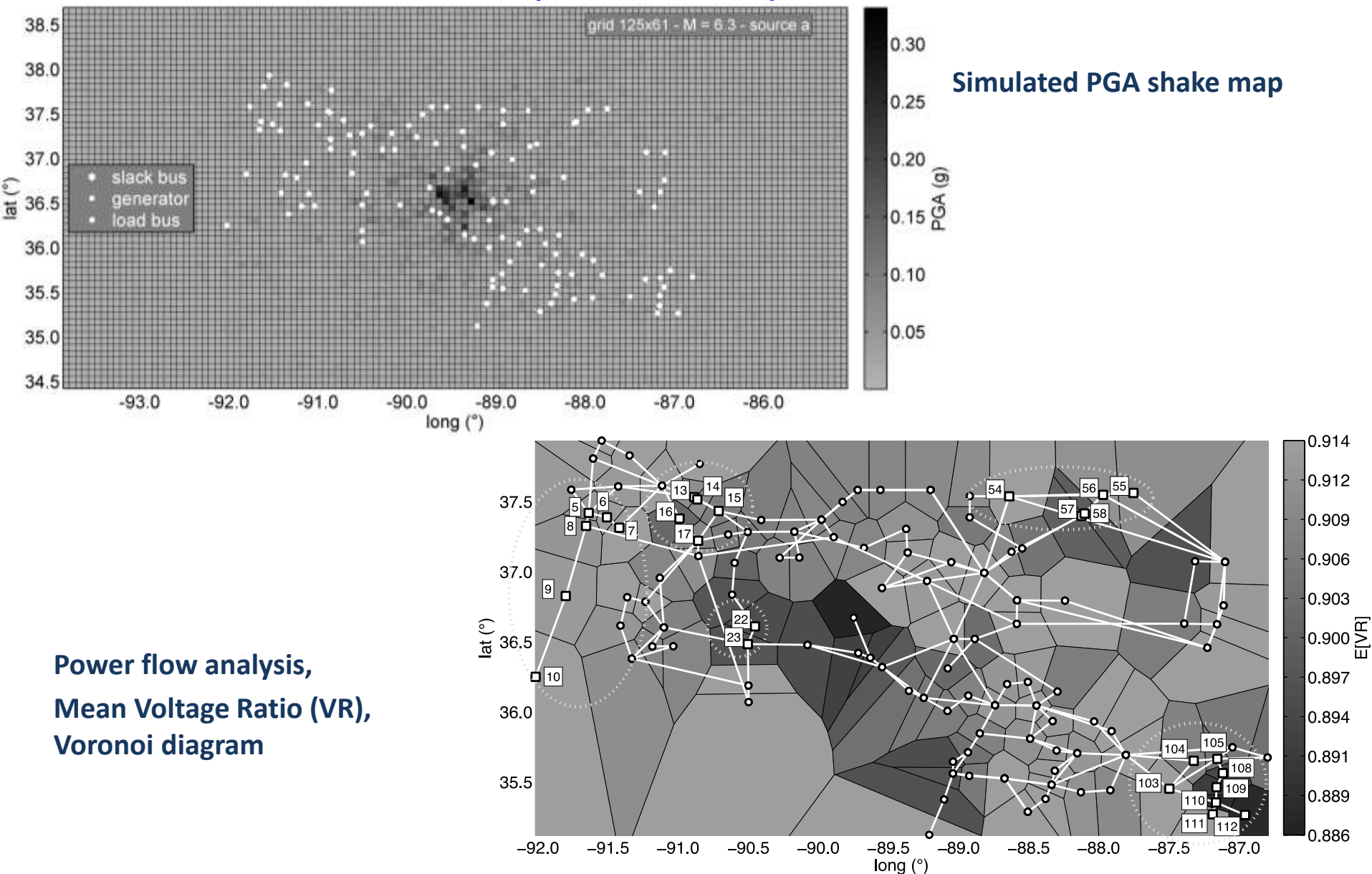
Case study #2: IEEE-118 bus power network



Electric power network case studies

Prediction of physical damage, connectivity and serviceability indicators

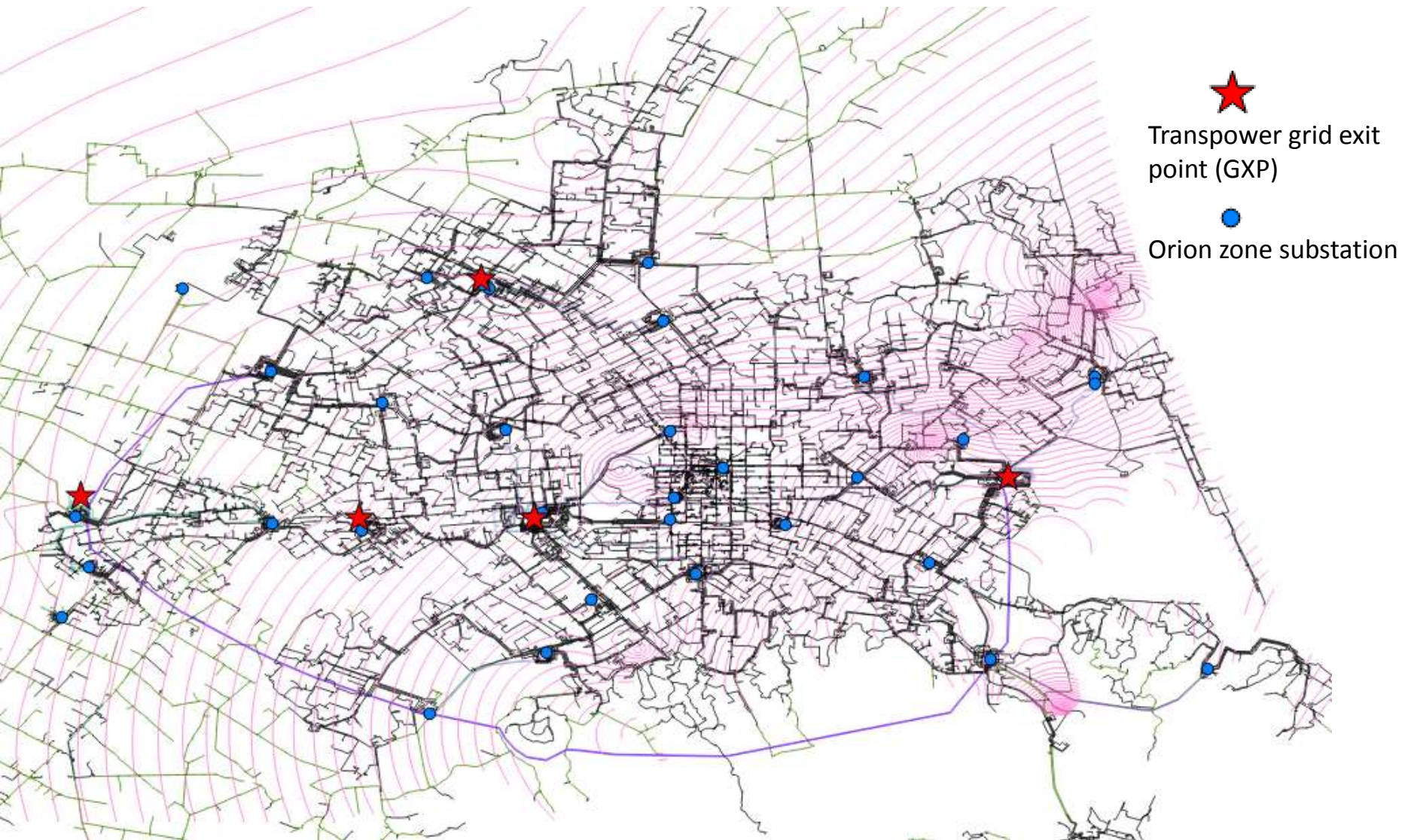
Case study #2: IEEE-118 bus power network



Christchurch electric power network

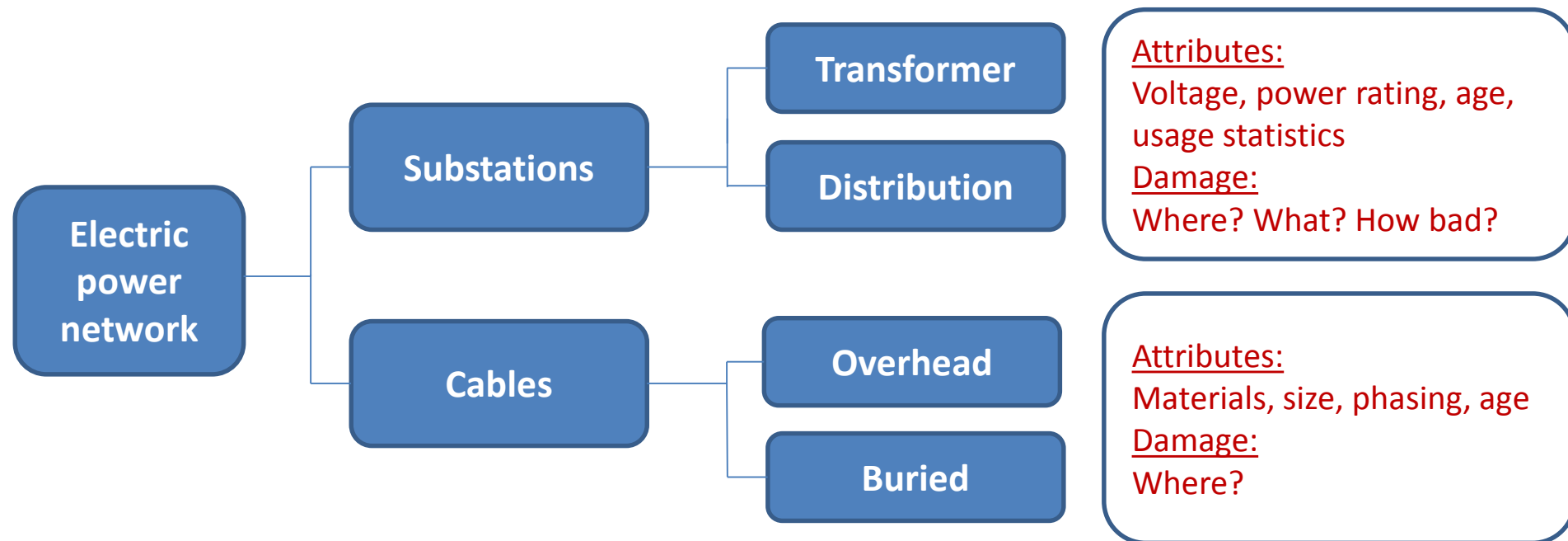
Prediction of physical damage, connectivity and serviceability indicators

Orion network with PGA shake map, Feb 2011 event



Lifelines data management

- *Pre-disaster: classify or 'inventorise' system into hierarchy of elements with locations and attributes*
- *Post-disaster: document damage occurrences and recovery activities*



Lifelines data management

Why is it important?

Vulnerability of elements

Risk assessment of system

Risk-based investment

Insurance

Emergency management

Learn lessons

What can improve?

Lack of standardisation

*Post-disaster data
collection*

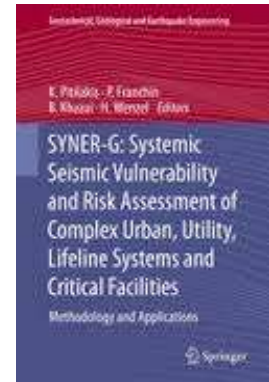
Interdependencies

Resilience aspects

- *robustness, redundancy, resourcefulness, rapidity*
- *technical, organisational, social*

Lifelines data management

Infrastructure system	Components	Component attributes
Electric power	Generation plants	Capacity, seismic design level
	Substations	Voltage, seismic design level
	Cables	Material, size
Potable water	Wells	Seismic design level
	Water treatment plants	Capacity, seismic design level
	Pumping stations	Capacity, seismic design level
	Storage tanks	Elevation, material, geometry, quantity of contents, seismic design level
	Pipelines	Material, joint type, age, diameter
Waste water	Lift stations	Capacity, seismic design level
	Treatment plants	Capacity, seismic design level
	Pipelines	Material, joint type, age, diameter
Natural gas	Pipelines	Material, joint type, age, diameter
	Compressor stations	Capacity, seismic design level
Fuel	Refineries	Capacity, seismic design level
	Pumping stations	Capacity, seismic design level
	Storage tanks	Elevation, material, geometry, quantity of contents, seismic design level
	Pipelines	Material, joint type, age, diameter
Telecommunications	Central offices	Seismic design level
	Cables	Material, size
Highways	Roadways	Importance level
	Bridges	Structural system, material, age, geometry, seismic design level
	Tunnels	Construction method, geometry, local geology
	Embankments	Height, soil type



Thank you for your attention

- Speaker contact details

- Dr Sonia Giovinazzi (sonia.giovinazzi@canterbury.ac.nz)
- Dr Deirdre Hart (deirdre.hart@canterbury.ac.nz)
- Dr Francesco Cavalieri (francesco.cavalieri@uniroma1.it)
- Indranil Kongar (indranil.kongar.10@ucl.ac.uk)

- Acknowledgements

NHRP

Natural Hazards Research Platform





Volcanic Ash Impacts Research – current and future

National Engineering Lifelines Forum

5 November 2014

Tom Wilson and volcanic impacts team

Volcanic Impacts Study Group – Auckland Lifelines Group

University of Canterbury, New Zealand

GNS Science, New Zealand

Massey University, New Zealand

University of Cambridge, United Kingdom

USGS, United States of America



Volcanic Ash Research -- Lifelines

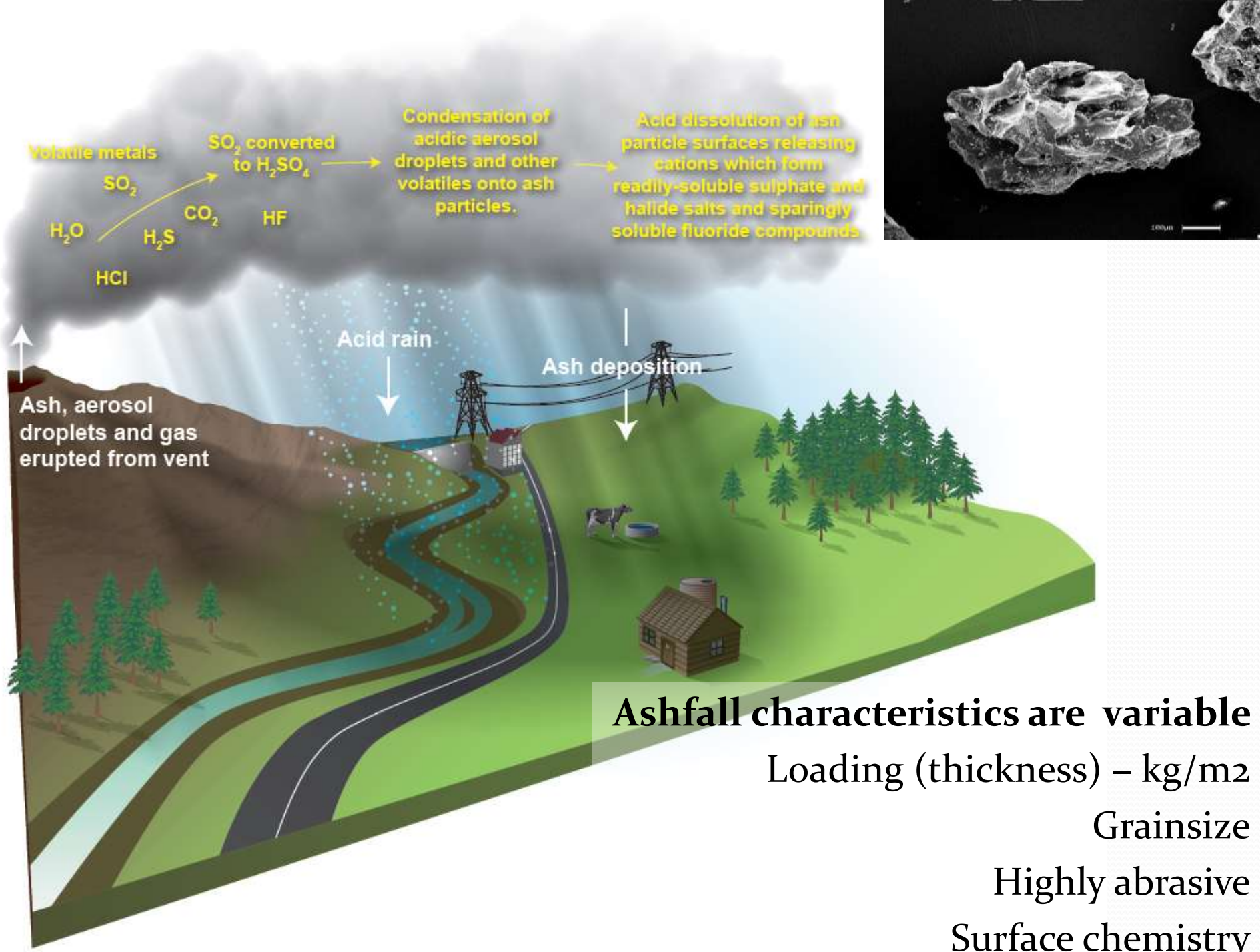
- Why worry?
- Current activities
- Case-study:
 - Volcanic risk to electricity systems
- International Contributions
- Resources Available



Why worry?



Shinmoedake 2011 Reuters



Ashfall characteristics are variable

Loading (thickness) – kg/m²

Grainsize

Highly abrasive

Surface chemistry

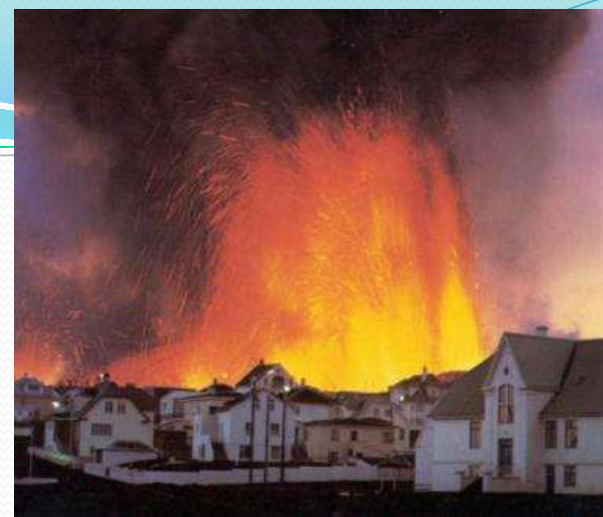
Why worry?

- Volcanic ash is the most likely volcanic hazard to affect the most people during an explosive eruption
- Volcanic eruptions can cause a range of impacts.
 - Exotic impacts. Mitigation options??
 - Potentially long duration, multi-stage, multi-hazard
- Infrequent eruptions
 - Limited opportunities to develop experience
 - So how do we learn?
- Limited knowledge base of impacts + mitigation compared to other perils
 - dominated by only several eruptions



Volcanic Impact Study Group

- Hosted by Auckland Lifelines Group
 - Subcommittee
 - National Focus
 - Researcher + practitioner membership
- Strong user-researcher partnership
 - strong culture of supporting research to practise
 - Multi-disciplinary
- Funding support for applied research project
 - Leveraging off larger Natural Hazard Research Platform + DEVORA funding

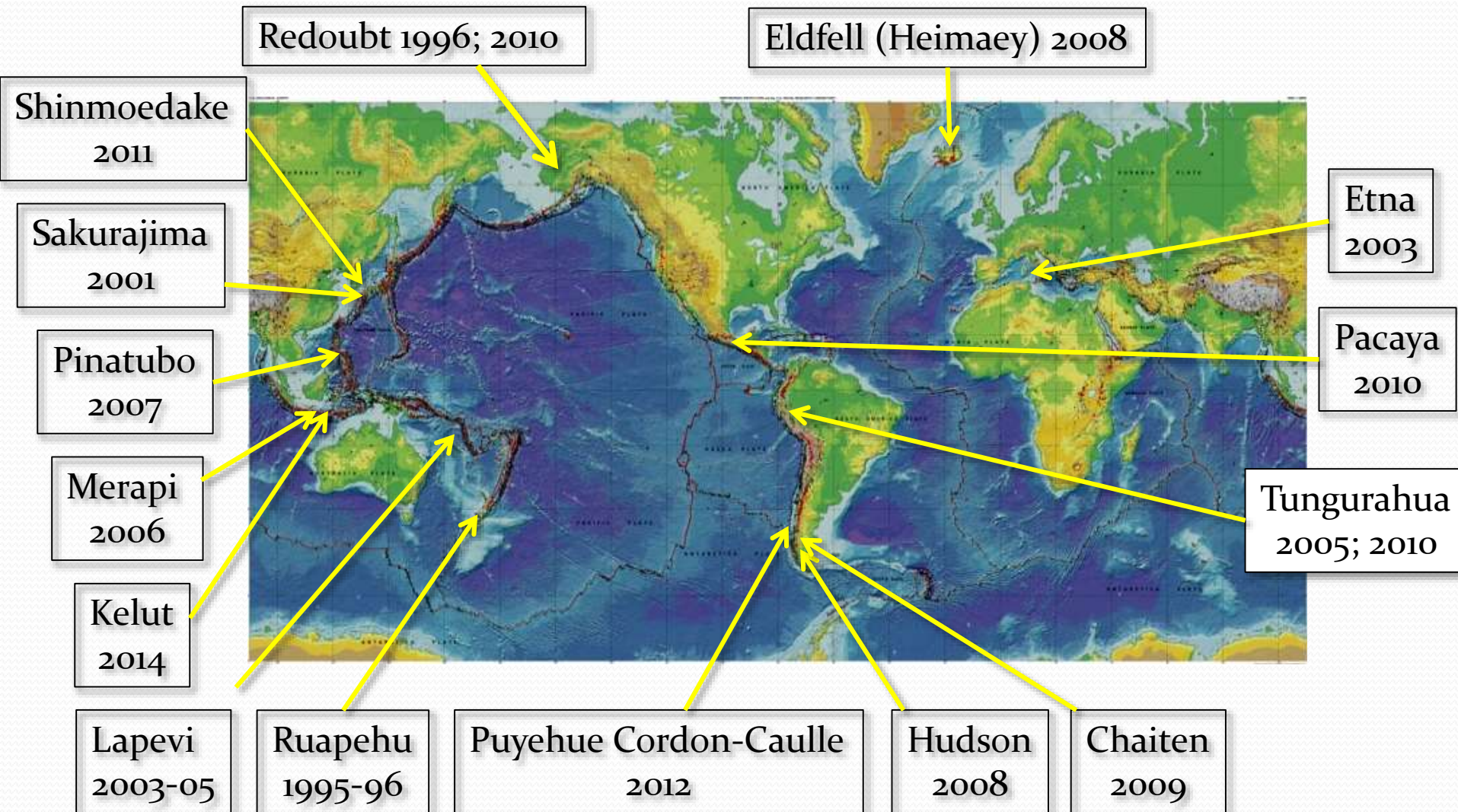


Research Context – Ash Impact Research

- Over the past 20 years our New Zealand research group (and collaborators) have aimed to undertake a sustained and systematic approach to volcanic impact assessment
 - critical infrastructure: **electricity, water supplies, wastewater, land and air transport, telecommunications**
 - ash cleanup and disposal
 - primary industries, e.g. agriculture
 - social impacts
 - emergency management

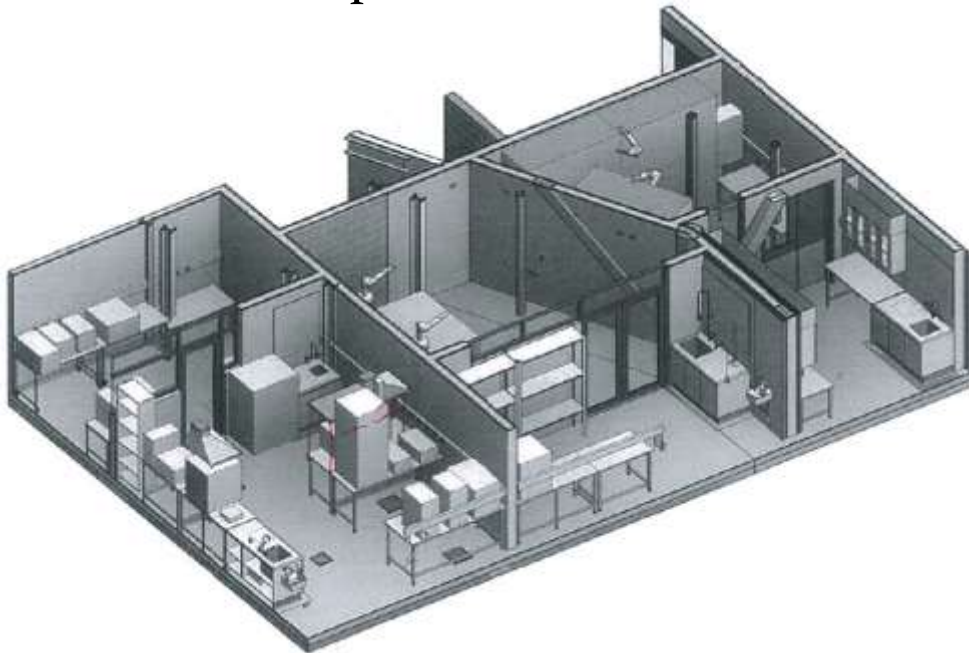


Addressing Knowledge Gap: Recon Trips



Addressing Knowledge Gap

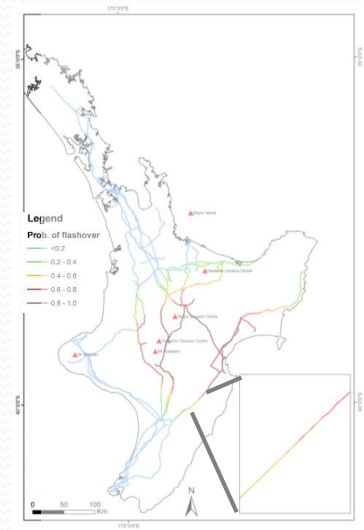
- Volcanic Ash Testing Lab (VATLab)
- Empirical experiments of components and systems which are vulnerable
 - Laboratory testing in controlled environment
 - Engineering College
 - UC re-development – investment



Fostering Research Partnerships

- **2009:** AELG-19: Impact of Ash on Electricity, Telecommunications, Broadcasting Networks
 - Electricity systems susceptible to ash fall induced outage
 - Identified knowledge gaps
 - Threshold for insulator flash-over?
 - What factors influenced resistivity of volcanic ash?
 - Resilient insulator design?

2008-2009



Case Study: Electricity Systems

The main impacts are:

- Supply outages from insulator flashover caused by ash contamination
- Disruption of generation facilities
- Controlled outages during tephra cleaning
- Abrasion and corrosion of exposed equipment
- Line breakage due to tephra loading



Ruapehu 1995



- Flashover and voltage fluctuation
- Exposed surfaces coated in 3mm of ash



Fostering Research Partnerships

- **2010-2013: PhD Project: Johnny Wardman**
 - Vulnerability of HV Transmission Systems to Volcanic Ashfall Hazards
 - Sponsor: Transpower Ltd.
 - \$140,000 + consumables
 - co-funding from NHRP



REVIEW ARTICLE
Potential impacts from tephra fall to electric power systems: a review and mitigation strategies
J. B. Wardman, T. M. Wilson, P. S. Rodger, J. M. Cole, C. S. Begg

Abstract: Modern society is highly dependent on a reliable electricity supply. During explosive volcanic eruptions, the contamination of power networks by volcanic ashfall presents a significant risk to the reliability of supply. This paper reviews the potential impacts of tephra fall on electric power systems, focusing on the vulnerability of power systems to ashfall. The paper reviews the potential impacts of tephra fall on electric power systems, focusing on the vulnerability of power systems to ashfall. The paper reviews the potential impacts of tephra fall on electric power systems, focusing on the vulnerability of power systems to ashfall.

Keywords: Volcanic Ashfall, Electric Power Systems, Vulnerability, Mitigation Strategies

1. INTRODUCTION
The potential impacts of volcanic ashfall on electric power systems are a significant concern for many countries. This paper reviews the potential impacts of tephra fall on electric power systems, focusing on the vulnerability of power systems to ashfall. The paper reviews the potential impacts of tephra fall on electric power systems, focusing on the vulnerability of power systems to ashfall.

ARTICLE IN PRESS
Physics and Chemistry of the Earth
Investigating the electrical conductivity of volcanic ash and power systems

J. B. Wardman, T. M. Wilson, P. S. Rodger, J. M. Cole, C. S. Begg

Abstract: The electrical conductivity of volcanic ash and power systems is a key parameter in understanding the potential impacts of volcanic ashfall on electric power systems. This paper reviews the potential impacts of tephra fall on electric power systems, focusing on the vulnerability of power systems to ashfall.

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Volcanic Ash Contamination: Limitations of the Standard ESDD Method for Classifying Pollution Severity
Johnny Wardman, Thomas Wilson, Department of Geological Sciences, University of Canterbury, Christchurch 8140, New Zealand

Abstract: The standard ESDD method for classifying pollution severity is a key parameter in understanding the potential impacts of volcanic ashfall on electric power systems. This paper reviews the potential impacts of tephra fall on electric power systems, focusing on the vulnerability of power systems to ashfall.

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Influence of Volcanic Ash Contamination on the Flashover Voltage of HVAC Outdoor Suspension Insulators
Johnny Wardman, Thomas Wilson, Department of Geological Sciences, University of Canterbury, Christchurch 8140, New Zealand

Abstract: The influence of volcanic ash contamination on the flashover voltage of HVAC outdoor suspension insulators is a key parameter in understanding the potential impacts of volcanic ashfall on electric power systems. This paper reviews the potential impacts of tephra fall on electric power systems, focusing on the vulnerability of power systems to ashfall.

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INSULATOR FLASHOVER

SUBSTATIONS

RECOMMENDED ACTIONS

- [illegible]



- [illegible]



Figure 4.10: A plot of the function $f(x) = \sin(x)$ for $x \in [0, 2\pi]$. The function is periodic with period 2π .

- Specialised inspectors are already present in the UK to inspect the following systems:
 - pressure transmitted HGV, pressure and sealed systems
 - lift and hoist for the security of installation ground work, moving materials into narrow shafts

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The above ground only is the common knowledge of the public and of the companies operating above ground only.

Source: The author.

- **Planning** = determining what actions are necessary to accomplish an organization's mission, vision, and strategy, and determining how to allocate resources to achieve those goals
- Planning is essential for the success of an organization
- Planning is a continuous process, not a one-time event
- Planning is a strategic activity, not a tactical activity
- Planning is a management function, not a technical function
- Planning is a leadership activity, not a follower activity
- Planning is a team activity, not an individual activity
- Planning is a process, not a product
- Planning is a framework, not a blueprint
- Planning is a guide, not a constraint
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1000

THE FOLLOWING INFORMATION SHOULD BE OBTAINED BY FIELDING OFFICERS:

<http://www.psu.edu>
<http://www.psu.edu>
<http://www.psu.edu>
<http://www.psu.edu>

References

- Implementing initiatives to support this plan means, however, that the use of public resources has increased
- A number of communities, among the wealthiest, are only just meeting required expenditure levels, and a number of others are well below
- While business are to some extent supported, it is the small, often family-owned, sector that is hardest hit



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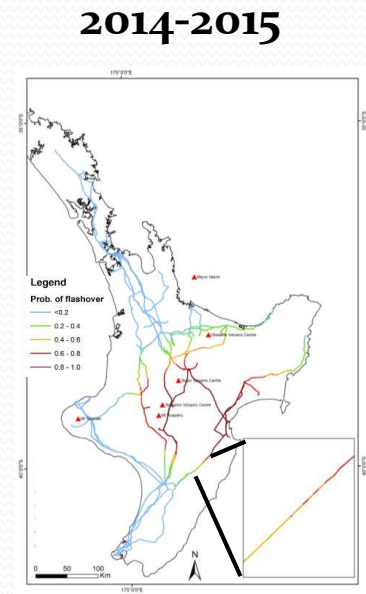
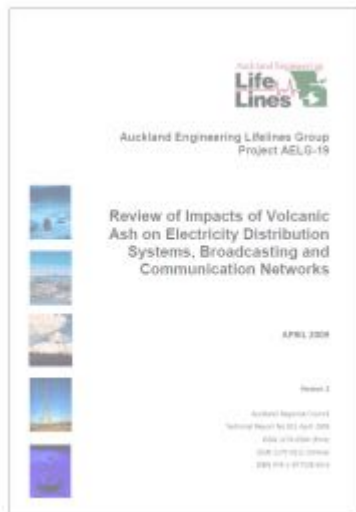
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- Aided Transpower volcanic risk management planning

Fostering Research Partnerships

- Volcanic Ashfall Risk on Critical Infrastructure
 - Probabilistic ash fall modelling
 - Refined impact thresholds for:
 - Transmission circuits
 - Grid Exit Points (GXP) – substations
 - Power Stations



- **2014: PhD Research Project:**
Grant Wilson

- **Risk Reduction**

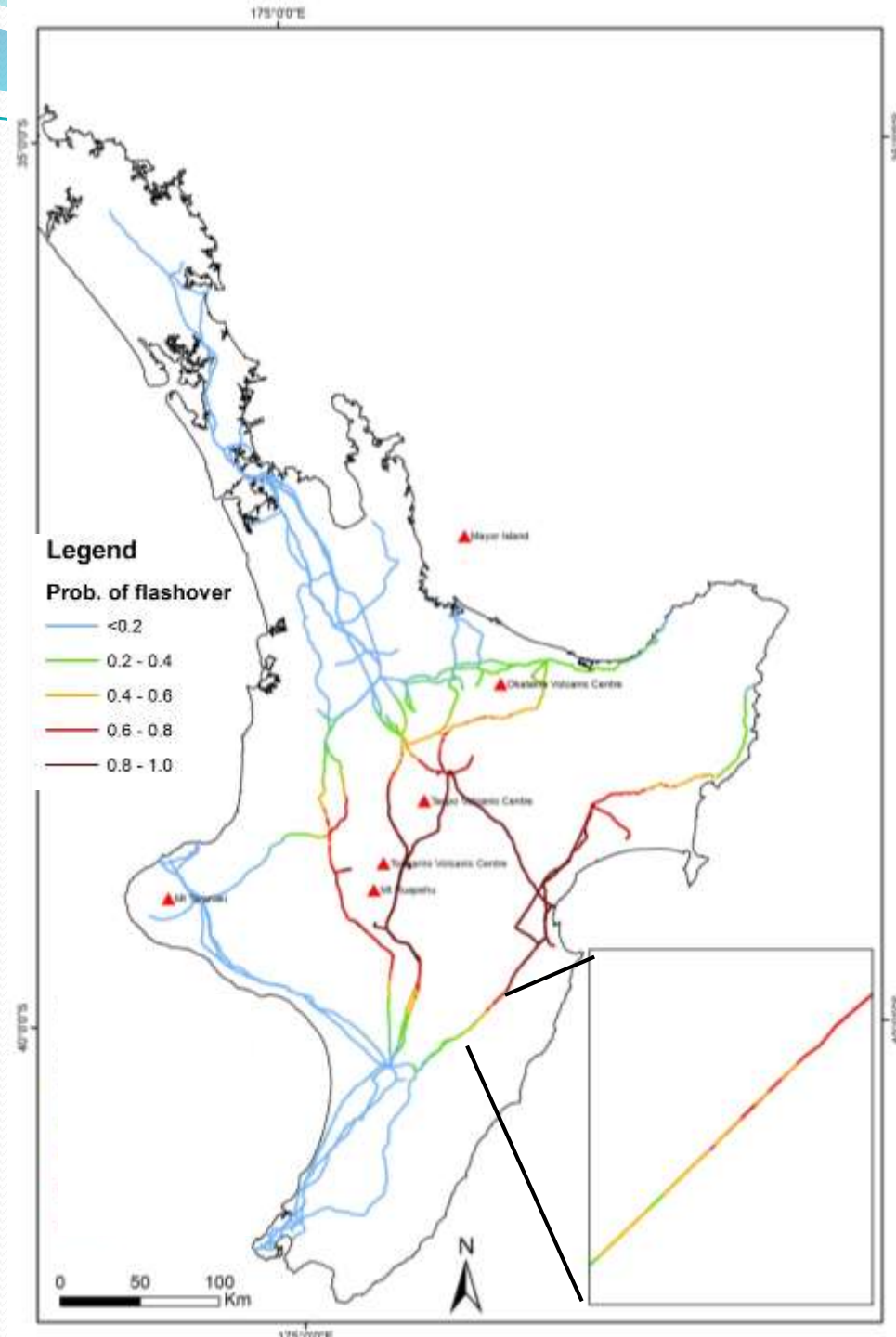
- E.g. locations for preventative mitigation
- Compare against other perils + account for uncertainty (probabilistic)

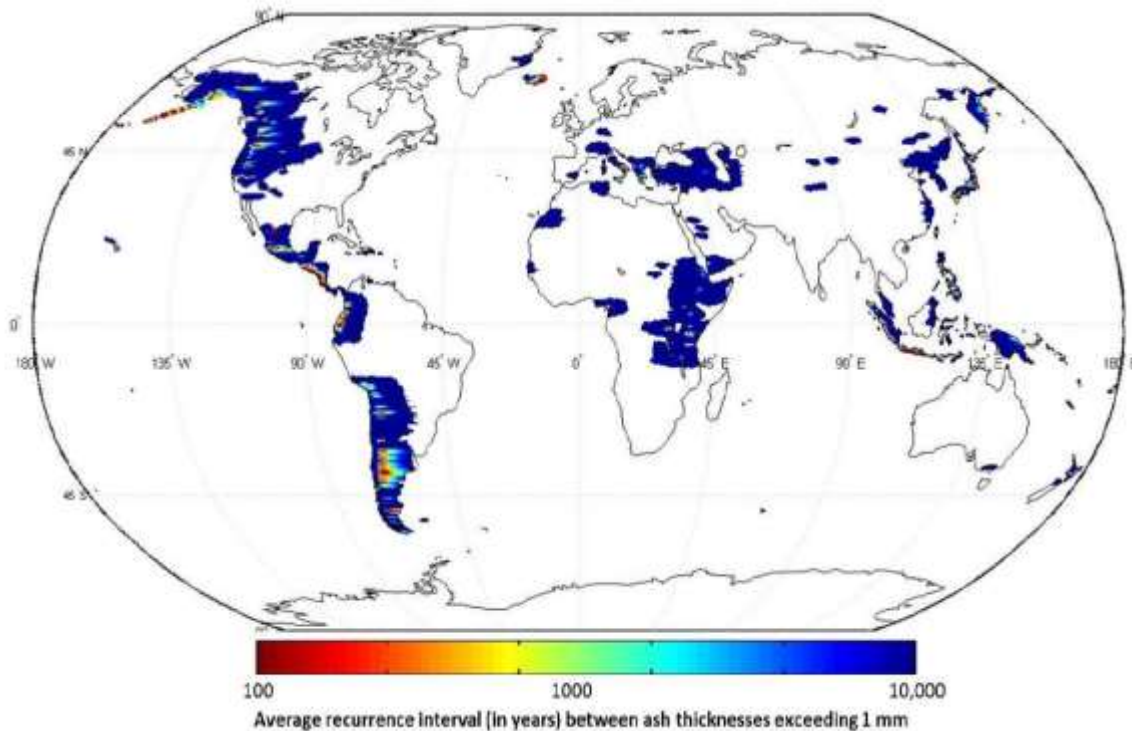
- **Readiness**

- E.g. prioritisation of cleaning

- **Response**

- E.g. deterministic scenario





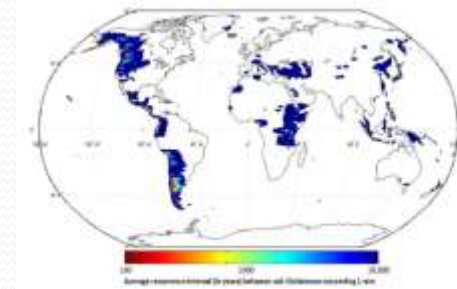
- UNISDR – Global Assessment Report (GAR-15)
 - Global ashfall hazard and risk modelling
 - Impact thresholds...scenario planning
- International partnership
 - South Korea (national scale assessment)
 - UK nuclear generator (site assessment)
- NZ Defence Technology – Aircraft Volcanic Ash Identification Protocol
 - UK + US civilian and military linkages

ities

IAEA Safety Standards
for protecting people and the environment

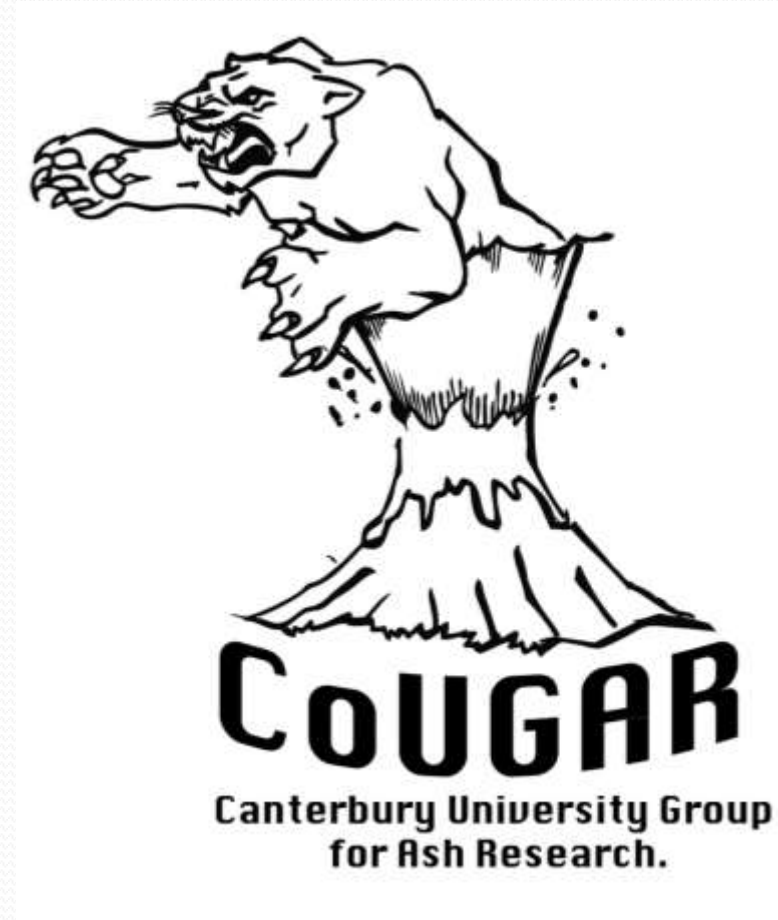
Volcanic Hazards in
Site Evaluation for
Nuclear Installations

Specific Safety Guide
No. SSG-21



- **Medium term Research Strategy**
 - Co-development of applied research projects
- **Impact/risk planning + response resources**
- **Natalia Deligne**
 - Presenting tomorrow

Thank you
Questions?



thomas.wilson@canterbury.ac.nz

Resilience research

Resilient cities are safer, more attractive to investors and new residents, and more able to recover quickly and with less loss of life and assets in the event of crises. UNISDR

Research initiatives

- Measuring the resilience of transport infrastructure (NZTA)
- Paper: Review of key terminology: risk, resilience, vulnerability, sustainability
- Canterbury lifelines: ongoing discussion around measurement / benchmark approaches.
- Internationally:
 - Rockefeller 100RC
 - UNISDR Resilient Cities Scorecard (MCR Campaign)
 - World Bank R!SE
 - UN Habitat CRPP

Reasons to Focus on Resilience



By 2050 over 70% of the World's population will live in Cities

Loss of life have decreased from Natural Disasters but....capital losses have exceeded \$2.5 T since 2000

Reasons to Focus on Resilience



Direct disaster losses are 50% higher than reported figures

Kobe port before the earthquake in 2005 was 6th busiest port in the world; By 2010 it had fallen to 47th despite massive investment.

Toyota lost \$1.2B in product revenue after the 2011 earthquake & tsunami

Reasons to Focus on Resilience



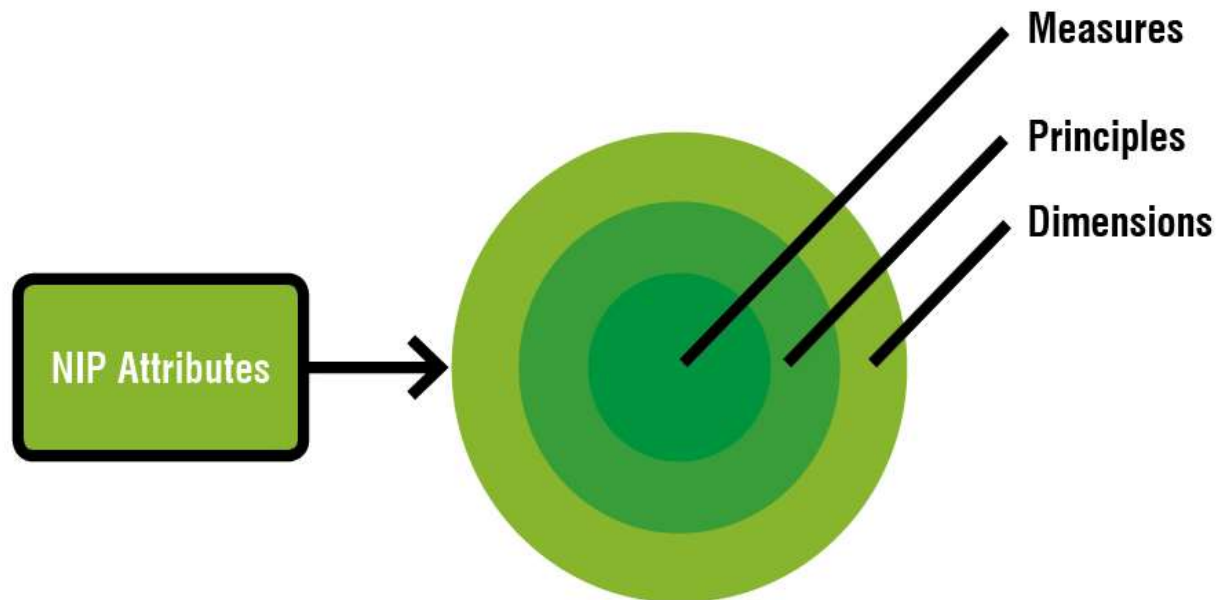
“Economic losses from disasters are out of control and can only be reduced with collaboration with the private sector”

Ban Ki-Moon
Secretary General of
the United Nations

Measuring transport resilience

Resilience framework

- Consists of *Dimensions*, *Principles* and specific *Measures* which can map to the NIP attributes if required.



How did we categorise resilience of infrastructure?

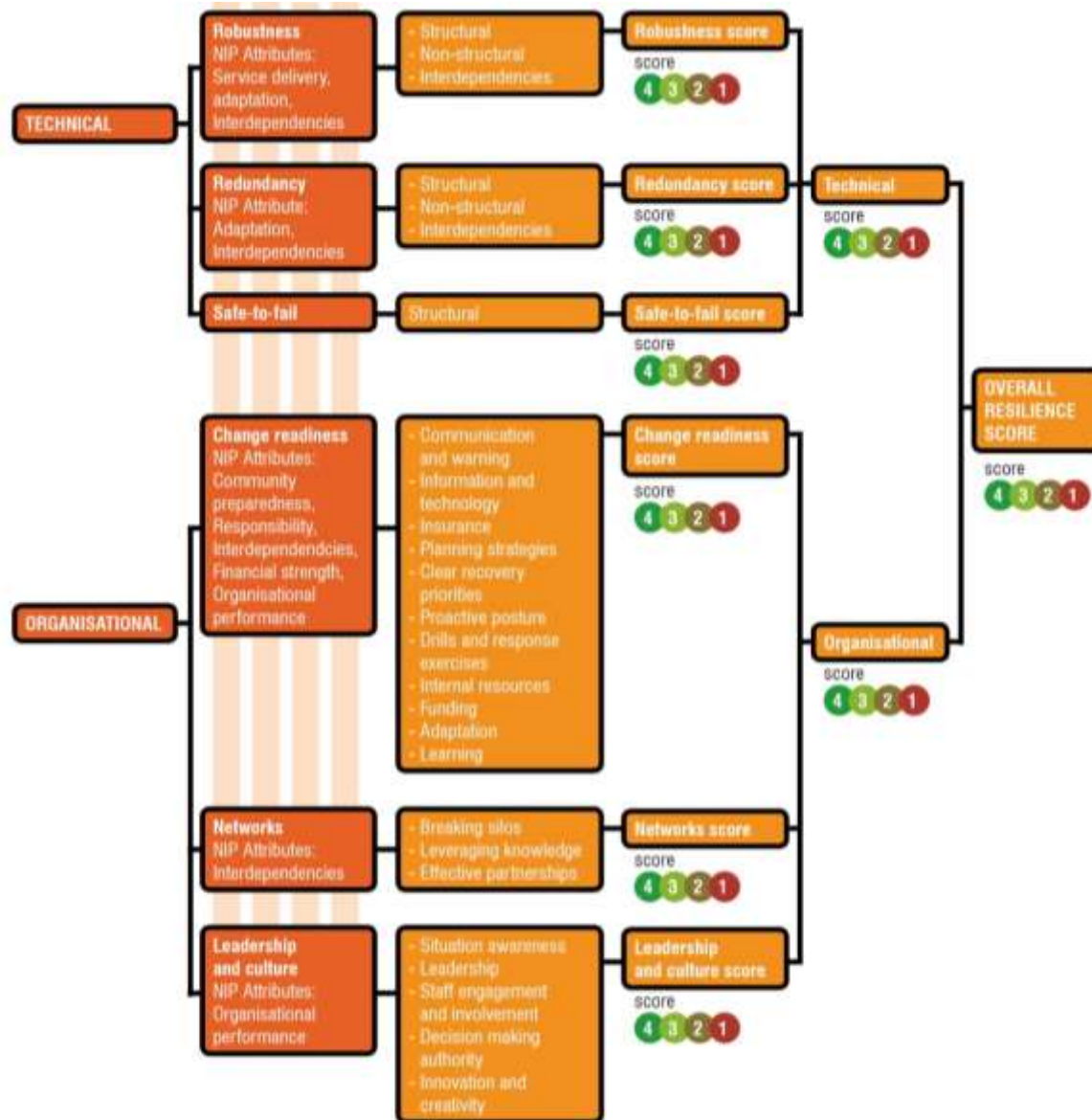
Dimension	Detail
Technical / Asset	The ability of the physical system(s) to perform to an acceptable/desired level when subject to a hazard event.
Organisational	The capacity of an organisation to make decisions and take actions to plan, manage and respond to a hazard event.

How did we categorise resilience of infrastructure?

Dimension	Principle	Categories
Technical / Asset	Robustness Redundancy Safe-to-fail	Measures
Organisational*	Change readiness Networks Leadership & Culture	Measures

**Refer work by Resorgs*

The measurement framework



Measures

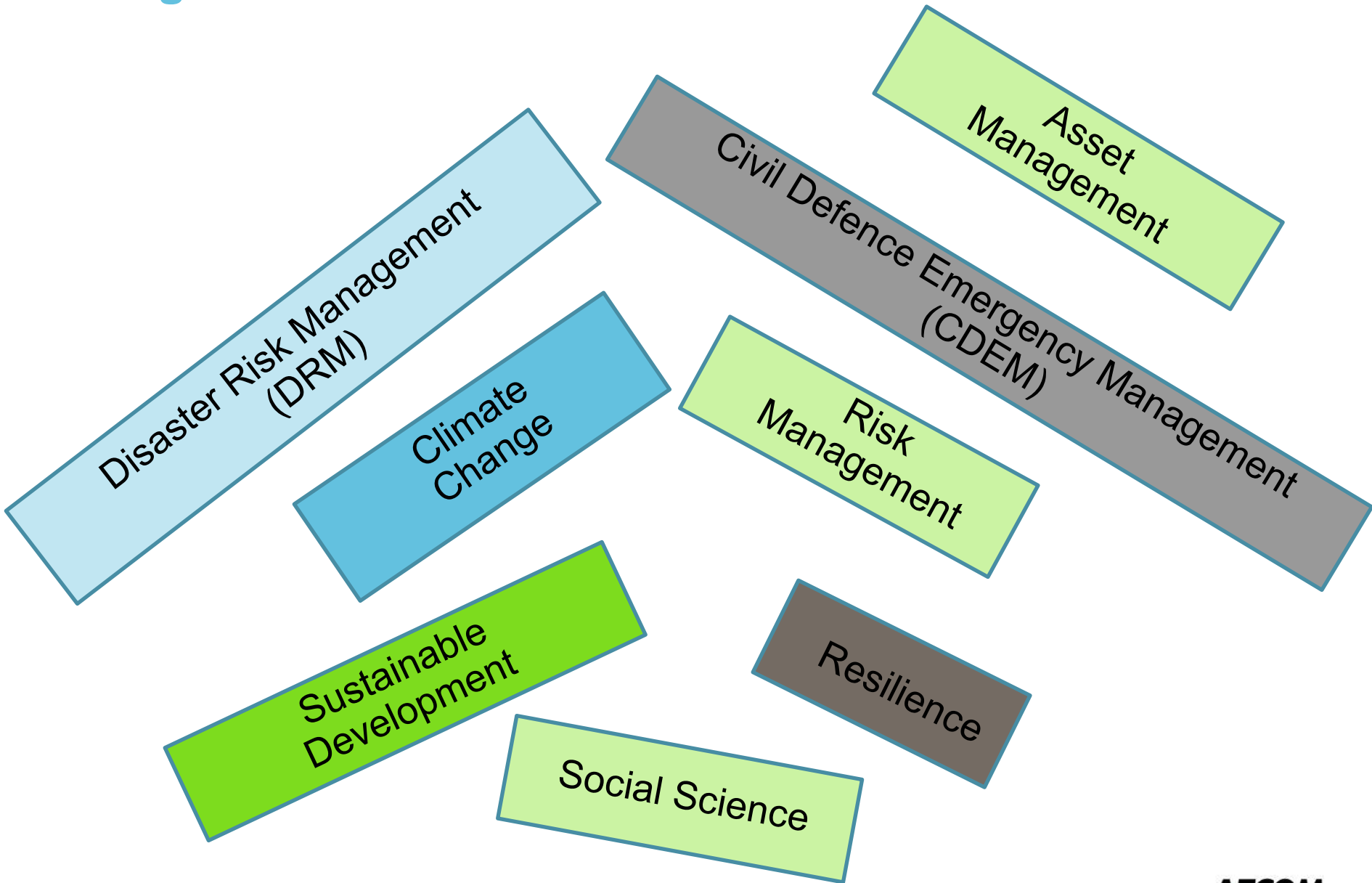
ROBUSTNESS				Weighted Robustness Score			
Category	Measure	Measurement	Measurement Scale	Individual Score	Category average	Weighting (%)	Weighted Score
Structural	Maintenance	Processes exist to maintain critical infrastructure and ensure integrity and operability - as per documented standards, policies & asset management plans (e.g. – roads maintained, flood banks maintained, stormwater systems are not blocked). Should prioritise critical assets as identified.	4 – Audited annual inspection process for critical assets and corrective maintenance completed when required. 3 – Non-audited annual inspection process for critical assets and corrective maintenance completed when required. 2 – Ad hoc inspections or corrective maintenance completed, but with delays/backlog. 1– No inspections or corrective maintenance not completed.	3	2.8	33.33%	94.4
		Evidence that planning for asset renewal and upgrades to improve resilience into system networks exist and are implemented.	4 – Renewal and upgrade plans exist for critical assets, are linked to resilience, and are reviewed, updated and implemented. 3 – Renewal and upgrade plans exist for critical assets and are linked to resilience, however no evidence that they are followed 2 – Plan is not linked to resilience, and an adhoc approach is undertaken 1– No plan exists and no proactive renewal or upgrades of assets.	4			
	Design	Percentage of assets that are at or below current codes	4 – 80%+ are at or above current codes 3 – 50-80% are at or above current codes 2 - 20-50% are at or above current codes 1 - nearly all are below current codes	3			
		Assessment of general condition of critical assets across region.	4 – 80%+ are considered good condition 3 – 50-80% are considered good condition 2 - 20-50% are considered good condition 1 - nearly all poor condition	3			
		Percentage of assets that are in zones/areas known to have exposure to hazards	4 – <20% have some exposure to known hazards 3 – 20-50% are highly exposed, or >50% are moderately exposed 2 - 50-80% are highly exposed 1 - 80%+ are highly exposed to a hazard	2			
		Percentage of critical assets with additional capacity over and above normal demand capacity	4 – 80%+ of critical assets have >50% spare capacity available 3 – 50-80% of critical assets have >50% spare capacity 2 - 20-50% of critical assets have >50% spare capacity 1 - 0-20% have spare capacity	2			

Research paper: hazard, risk,
resilience, vulnerability

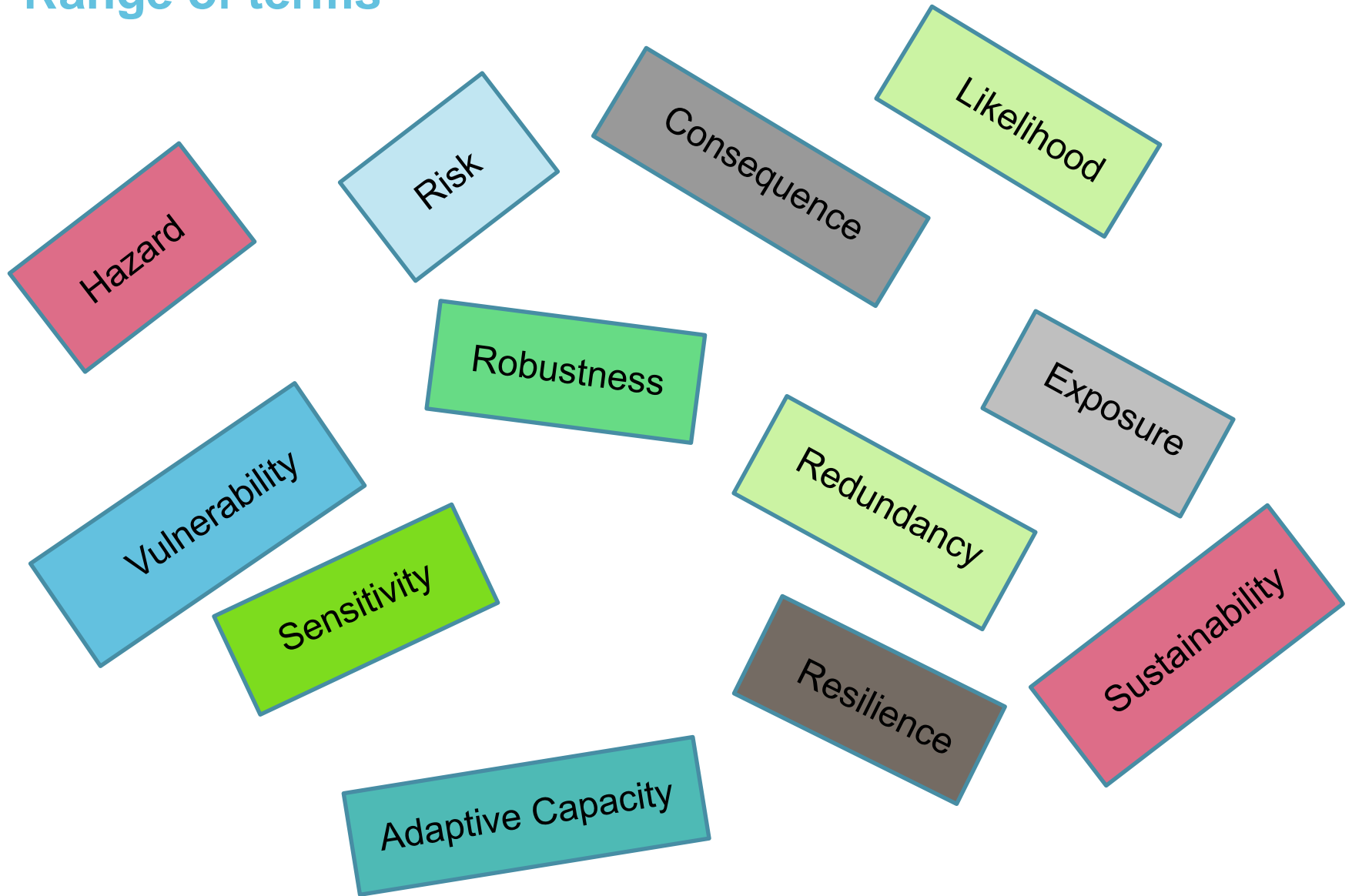
We investigated

- Consistency across risk management approaches?
- Confusion in terminology - and suggestions for simplification
- Risk approaches vs resilience approaches. What are differences? When to use?
- Recommendations for asset management field and implications for other fields

Range of fields



Range of terms



Links

- NZTA Research:

<http://www.nzta.govt.nz/resources/research/reports/546/>

- Paper on risk, resilience and terminology: Come and see me: james.hughes@aecom.com

Thankyou

*“Whilst systems have commonly been designed to be **robust** (designed to prevent failure), increasing complexity and the difficulty it poses to fail-proof planning have made a shift to "resilience" strategically imperative.*

A resilient system on the other hand accepts that failure is inevitable and focuses instead on early discovery and fast recovery from failure”.

David Snowden